ALLIS-CHALMERS

ELECTRICAL REVIEW

S. R. Durand

June • 1942

Low-current welding saves many man-hours in fabrication of thin structural parts. Here stainless steel vats are being produced.

SAVED! COPPER AND MAN-HOURS

REQUIRING A MINIMUM OF COPPER AND man-hours, Allis-Chalmers ⅝% Step Regulators help keep production at capacity in the nation's industrial plants.

FOR THE VICTORY EFFORT!

Allis-Chalmers ⅝% Step Regulators Raise Voltage on Overloaded Lines! . . . And Do It with a Big Saving in Man-Hours and Copper!

Have you, like many systems, had trouble maintaining voltage on overloaded lines? Here are facts that add up to real savings in two vital war materials — man-hours and copper!

This is what actually happened on a southern system, where, on a long run of light copper, rising loads had reduced the voltage below allowable limits. There were four possible ways to correct this condition . . .

1 Convert the delta system to wye. This required a fourth No. 4 copper wire, or 19,960 lb of copper.

2 Replace existing 13 miles of No. 4 with No. 00 copper wire. Crediting 26,190 lb of No. 4 wire, this meant an additional *47,160 lb of copper.*

3 Wire wrapping with No. 4 wire around 13 miles of existing conductors — *26,190 lb of copper.*

4 Installing a 120 kva, three-phase, 13,800 volt Allis-Chalmers ⅝% Step Regulator, requiring *only a few hundred pounds of copper.*

This southern system purchased the Allis-Chalmers Regulator. Not only did they conserve hard-to-get copper — they also reduced the number of man-hours required to make the change.

What's more, the regulator takes care of fluctuating source voltage and compensates for reactance as well as resistance drop. And, if the loads shift, the Allis-Chalmers AFR can be moved where it is needed.

Remember, you can accomplish savings of vital material with Allis-Chalmers ⅝% Step Regulators. And *only* with Allis-Chalmers Regulators can you get the five engineering advancements shown here!

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A 1504

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ALLIS-CHALMERS ELECTRICAL REVIEW

C O N T E N T S

POWER FOR PORTLAND CEMENT
I. OUT OF LIME AND CLAY*

Lowly clay and common limestone are the materials from which man has erected some of his proudest achievements. In portland cement they are the raw materials for roads, dams, bridges, buildings. And the power required to manufacture cement . . . 2% of the nation's output . . . is a vital load on many systems.

J. M. Wolfe

CRUSHING & CEMENT DIVISION • ALLIS-CHALMERS MANUFACTURING COMPANY

Portland cement ranks next to steel as the most important engineering material for building and construction. Engineers, whether by formal training or by experience, understand the basic processes used in smelting ore in the production of iron and the subsequent processes used in the manufacture of steel. In the curricula of many technical schools, however, a course devoted to the manufacture of portland cement is not included; and, where the subject is taught, the course is usually brief.

The purpose of this article is to present features of cement manufacture that may be of interest to electrical engineers.

The specifications of the American Society for Testing Materials, Designation C 74-36, define portland cement as ". . . the product obtained by pulverizing clinker, consisting essentially of calcium silicates, to which no additions have been made subsequent to calcination other than water and/or untreated calcium sulphate, except that additions not to exceed one percent of other materials may be added, provided such materials have been shown not to be harmful by tests prescribed . . ."

The discovery of portland cement, first known in England, is attributed to Joseph Aspdin, a bricklayer, who in 1824 took out a patent for an improved cement which he called "portland cement" because it resembled a building stone quarried on the Isle of Portland.

The earliest American production dates from 1871, when David O. Saylor of Allentown, Pennsylvania, took out a patent for an "improved cement." He had found that the chemical composition of the particular limestone investigated approached closely the analysis of the raw mix that was used in making European portland cement, which was then being imported into the United States. Saylor became the first commercially successful manufacturer of portland cement in the United States.

A modern cement plant expends about 21 kwh of electrical energy in the production of one standard 376 lb barrel of normal portland cement. This power may be accounted for in six major phases of the complete process, beginning at the quarry and clay pit, where electric shovels dig and load the raw materials, and ending at the semi-automatic, electric motor-operated packing machine which fills sacks to the standard weight of 94 lb.

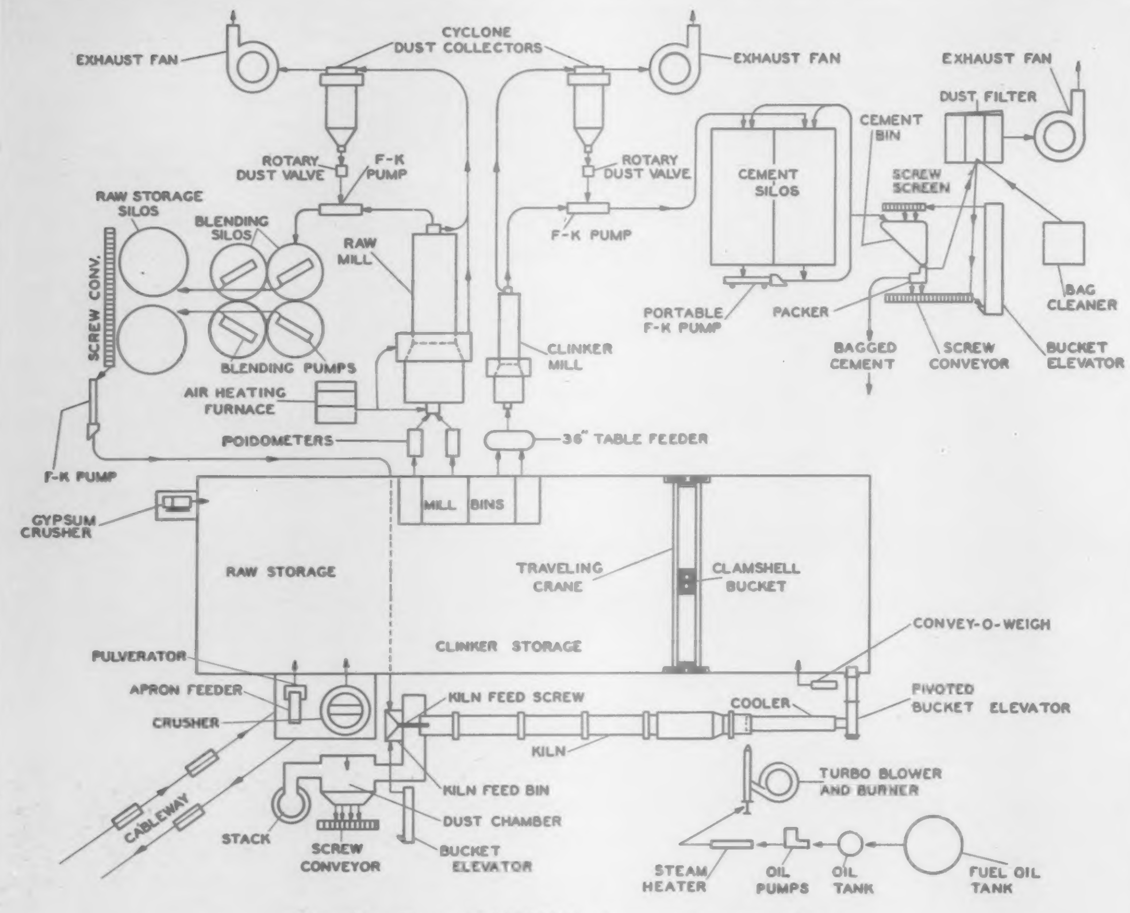
Raw materials

Limestone and clay are the most common raw materials used in cement manufacture, but these have relatively small intrinsic worth because of their abundant and extensive occurrence in the earth's surface. Not all kinds of limestone and clay are chemically suitable, and whatever commercial value applies to these materials in their natural state arises from their utilization in many industrial fields. In the manufacture of portland cement, however, limestone and clay—or, in some operations, shale — are the essential raw materials. Blast furnace slag and limestone are used in certain instances where the cement plant is located close to iron smelting operations.

A large percentage of the cost of producing a barrel of portland cement is chargeable to the electrical energy required. A very large percentage of the total electrical energy consumed is used in finely grinding the raw materials prior to burning them in the rotary kiln and in grinding the coarsely granular product from the kiln, called clinker, to extreme fineness, thus endowing the material with cementitious properties.

* The first of two articles dealing with the method of and power requirements for manufacture of portland cement.

AT LEFT: Millions of yards of concrete go into this giant dam — an example of the part portland cement plays in the battle of production.



Flow sheet of a typical 1200 bbl., dry-process cement plant.

While there probably are more motors smaller than 25 hp than there are above that rating in the average cement plant, the amount of energy used by motors 25 hp and larger is considerably greater than the amount of energy used by the smaller motors. The smaller motors are used to drive machines which perform the functions of conveying, elevating, mixing and pumping as well as to actuate auxiliary devices which operate in conjunction with the principal machines.

Power requirements huge

Appreciation of the quantity of electrical energy consumed in a year by portland cement plants with the industry operating at about two-thirds of its rated capacity, as it was in 1940, may be obtained by a comparison with total power consumption figures for the United States.

In July, 1940 (a month of substantial industrial production), approximately 2,600,000,000 kwh of electrical energy were required during each week to meet industrial and domestic demands. The total output of cement in a year of similar prosperity may be taken as 140,000,000 bbl, each of 376 lb.

The production of cement for 1940, for the purpose, may be assumed to be standard portland, the manufacture of which, in a modern plant equipped with electrical devices for regulation and control, requires about 21 kwh per bbl. On this basis the yearly electrical power consumption for the cement industry would have been approximately 2,940,000,000 kwh. Thus, about 1/50 of the total electrical energy consumed by the nation for both domestic and industrial purposes is expended in the manufacture of cement.

It may be explained that cement clinker and the raw materials required for its manufacture are usually ground in compartment mills. These mills are, essentially, cylindrical chambers in which metallic grinding media, usually balls and other metallic elements, are used to grind the materials.

Methods of grinding

In certain instances raw materials and clinker are ground in two-stage grinding mills. Two-stage grind-

ing, as the name implies, employs two separate mills instead of one compartment mill. In the compartment mill preliminary and finish grinding are carried on in one mill. In the two-stage system, preliminary grinding is carried on in a separate ball mill with the length of the grinding chamber approximately equal to its diameter, and finish grinding is done in a separate mill of somewhat smaller diameter and of greater length.

In the preliminary grinding ball mill, and in the primary chamber of the compartment mill also, forged steel balls of assorted sizes with diameters as great as 4 in. or 4½ in. are used. In the secondary or finish grinding mill, or the secondary chambers of the compartment mill, smaller grinding bodies are used, which may consist of forged steel or chilled cast iron balls or forged steel or chilled iron concavo-convex grinding media.

Power is applied to revolve the mill grinding chamber at a fixed rate of speed so that a large proportion of the grinding media is lifted through a vertical distance nearly equal to the internal diameter of the mill. In falling or cascading within the chamber, the coarse materials are ground to a fine powder.

Since grinding accounts for a major part of the electrical energy consumed in the manufacture of portland cement, in estimating the power consumed per barrel, the fineness to which raw materials and clinker are ground is a very important factor. There is a direct relation between energy consumed and the fineness of grinding.

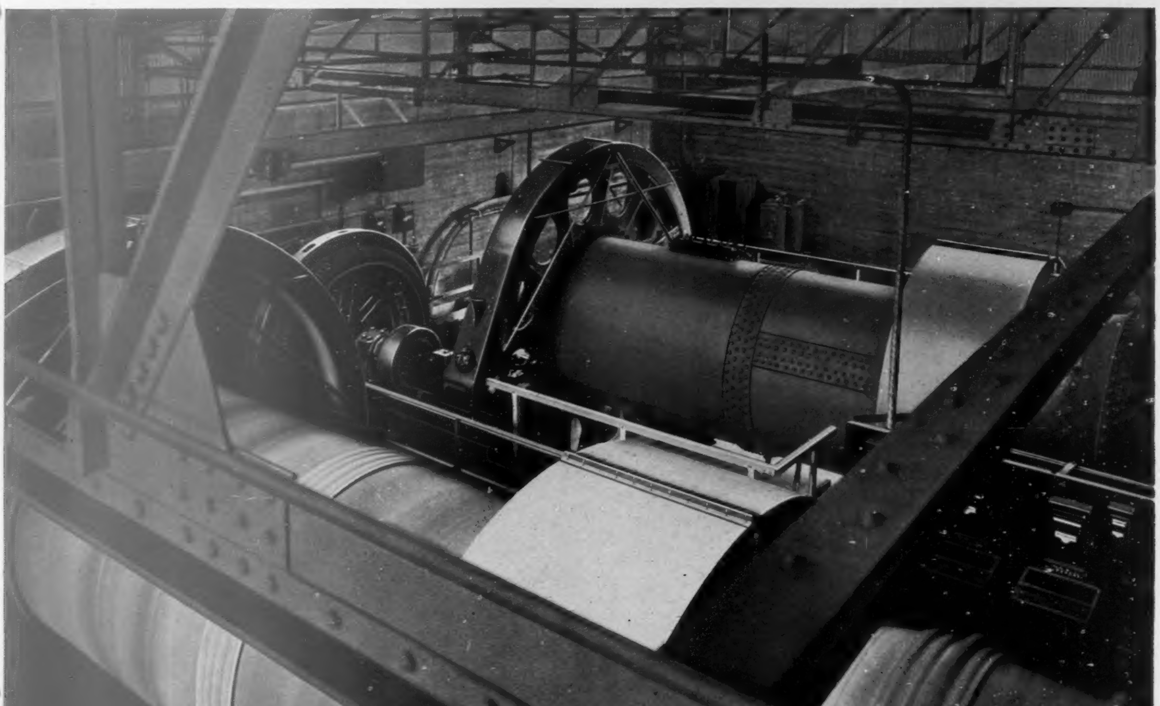
Power demands and cement fineness are directly inter-related, and the energy expended in grinding is directly proportional to the new surface exposed by reduction in the particle size. Based on experience and the data from laboratory grinding experiments, the rating of the motor to drive a grinding mill may be calculated.

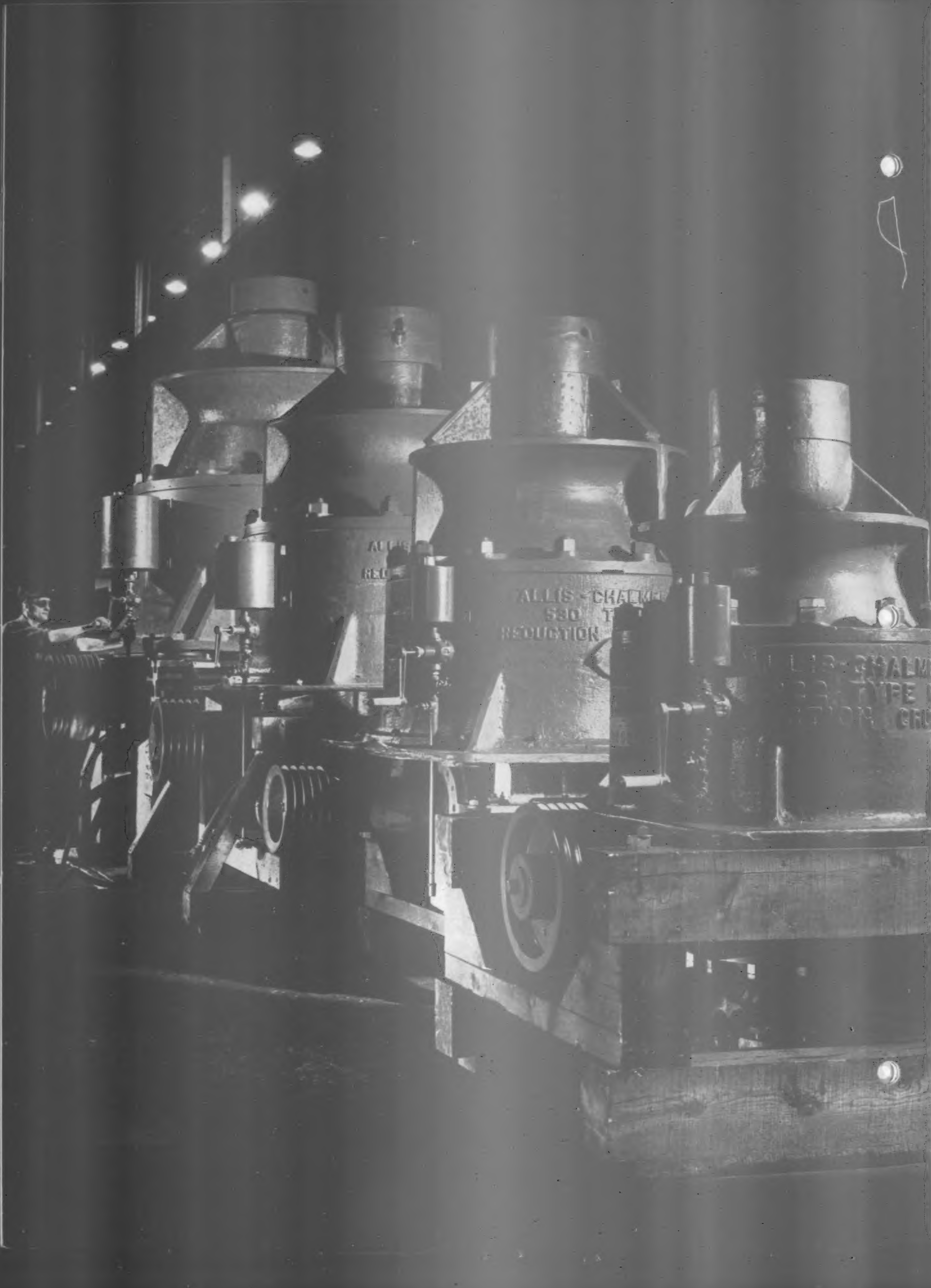
In producing high early strength portland cement, which is a special cement ground to great fineness, certain machines, auxiliary to the mill, such as air classifiers, spiral conveyors, and elevators, are employed in the grinding circuit. The power required to drive the auxiliary equipment in addition to power consumed in the mill itself, with special operations of raw material control and subsequent burning, increases the production cost of high early strength portland cement.

Closed circuit operation

In many cases grinding mills are operated in closed circuit. Closed circuit grinding, as the name implies, employs the principle that mill capacity is increased

Raw compartment ball mills are driven by 550 hp. direct-connected synchronous motors in a Pennsylvania cement plant.

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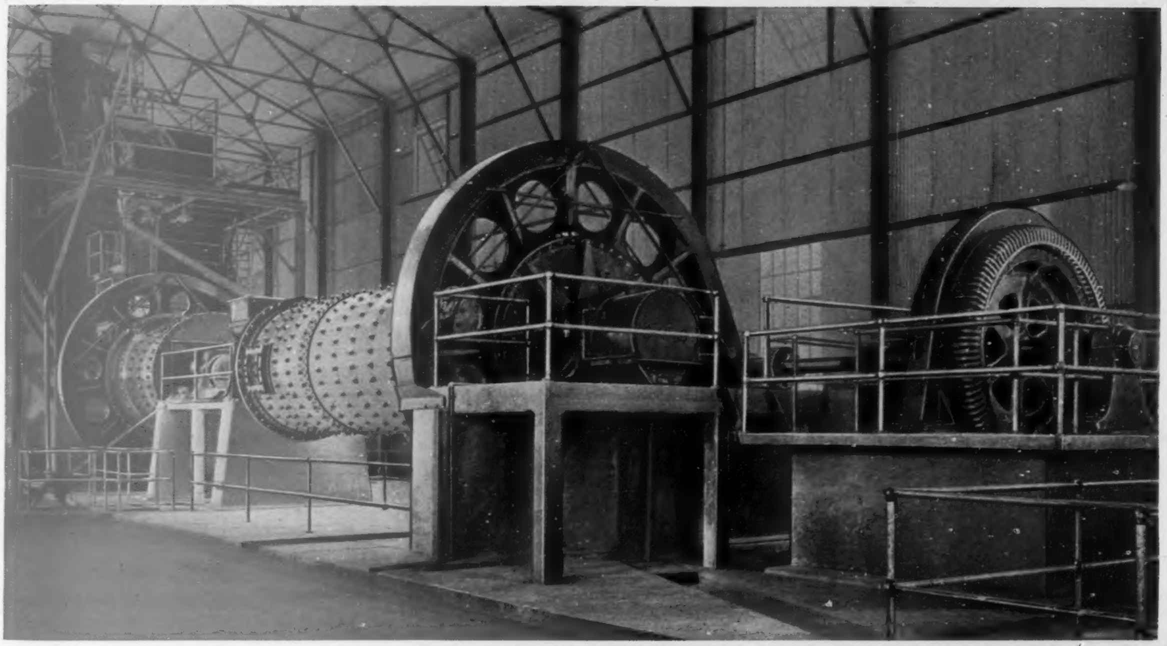
REDUCTION



Synchronous motor driving a secondary mill in South Africa. In the background is shown the raw grinding preliminary mill.

by classifying the product in auxiliary equipment and returning the oversize to the mill for regrinding. An air separator is employed as the classifier in dry grinding. The classifier used for wet grinding may be mechanical, hydraulic, or a combination of the two types. The classified, or finished product, is the product of the mill classifier unit.

In grinding raw materials, the desired goal is uniformity of particle size rather than maximum surface area. Raw cement materials, therefore, lend themselves to closed circuit grinding, which results in a decrease in overall power requirements for the mill-classifier stated in terms of a unit of production. It may be said that in grinding operations, both wet and dry, power requirements may be reduced by closed circuit grinding.

In the grinding of cement clinker to make portland cement (after the raw material has been burned in a rotary kiln), the surface area of the product is the basis of fineness measurement. In this grinding operation various other systems employing air separation have been developed. These systems, or circuits as they are usually called, were developed for fineness control and also to reduce as much as possible the unit power consumption where a product of extreme fineness is required.

Effect of load factor

A consideration affecting the entire cement plant is the electrical load factor. When this load factor is multiplied by the total connected load of the plant in terms of kw and is divided by the barrels of cement per hour, the result, in kwh per barrel, may be used to compare the electrical efficiency of the plant with that of other plants of a similar capacity if the plants compared are treating similar materials and are manufacturing cement of equal specifications.

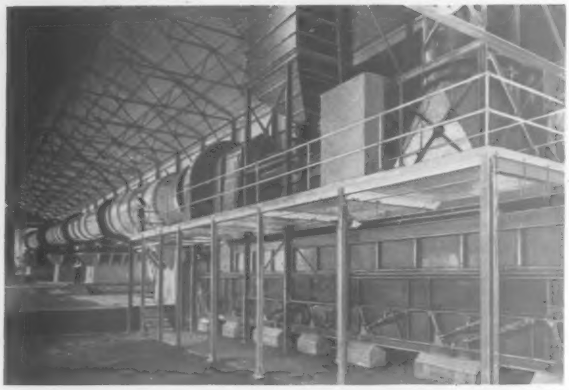
The value of the load factor of any plant is important to its designers and operating staff because no two plants of equal production rating, manufacturing similar grades of cement, are designed with exactly the same amount of connected motor horsepower. Thus, one 1,200 barrel plant may contain motors totalling 2,100 hp, whereas the total of another may differ by as much as 400 hp.

The contributing factors which influence such a wide variation are those upon which the cement plant engineer predicates his design and layout; namely, in part, terrain, source and character of raw materials, type of plant (i. e., whether the wet or dry process is employed), source of power (plant-generated or purchased), size and type of the principal and accessory equipment.

Furthermore, since auxiliary machines which perform the functions of conveying, elevating, feeding, pumping, etc., are often selected to serve double the number of processing units installed initially, to provide for future plant expansion, the connected load may be inordinately high with respect to the capacity of the plant.

It is in line with sound economics when designing a new plant to provide oversize auxiliary apparatus

AT LEFT: In crushing of both raw and finished product, considerable electric power is used. Shown are several sizes of a modern fine reduction gyratory crusher. The largest unit is being tested.



More motor horsepower is needed to drive rotary kilns like this wet process unit with modern air quenching clinker cooler.

against an anticipated duplication of cement-making units, i. e., kiln, cooler, and mills. This practice is one reason why it is not feasible to define an inflexible relationship between connected load and production capacity. Nearly ideal conditions may permit a reduced connected load with motors operating within very close limits of their nominal ratings.

Power factor important

The power factor is always important, regardless of the load factor. High power factor is generally obtained in modern cement plants by the use of synchronous motors for driving the grinding mills. Under certain conditions a low load factor during peak hours may be desirable both for the power company and for the cement company. Where no demand charge is made for excess power during off-peak hours, it is often desirable to install excess grinding capacity.

Under such conditions the net rate per kwh will be reduced, and the power company will be enabled to furnish a greater total amount of electrical energy by obtaining a better load factor for the power plant.

In a well designed and organized cement plant in which all extensions have been anticipated on the basis of the initial installation, the load factor should be about 75 percent.

Although it is obviously quite a hopeless task to standardize cement plants, yet orderliness and direction accompany the development of their design when the salient factors are known. The following figures are presented not as a basis for interpolation but to illustrate these variations:

In an 11,000 bbl per day plant the connected motor load may be as low as 11,000 hp or in the ratio of 1 hp per bbl; whereas, in a 1,100 bbl plant the ratio may approach 2 hp per bbl.

From the foregoing, since application of power markedly affects plant efficiency, it will be seen that electric power is a very considerable item in the cost of production; and proper and careful analysis should be made by an electrical engineer, or his experience should be employed by the cement plant designer with reference to selection of electrical equipment.

Today electric power is used universally by the cement industry on account of its flexibility, permitting shutdowns of some plant sections while production continues in others. It reduces periods of involuntary interruption of manufacture in an industry where continuous operation is required to preserve product uniformity to meet rigid specifications. Further, the means of its distribution and utilization leave a wide latitude in formulating plans for alterations in existing plant layouts and extensions.

Lastly, an alert management will certainly want to know how much power is consumed in accomplishing the various steps of manufacture, especially in grinding, which is a continuous and costly operation. Electric power lends itself readily to the measurement and subsequent recording of departmental energy requirements, which is a valuable aid to efficient plant management.

Process of manufacture

A brief description of the cement manufacturing process at this point will clarify succeeding discussion of motor applications according to the character of the operation involved and of the considerations which govern the sources of power for the cement plant.

It will be assumed, for purpose of this illustration, that limestone and clay are basic raw materials, although other calcareous argillaceous, and siliceous materials, which in proper proportions form a suitable raw material mixture, may be utilized. The steps in the manufacture of portland cement in a modern wet process plant, equipped with efficient machinery and having a rated productive capacity of 1,200 bbl per 24-hour day, will be outlined.

Reference to the wet or dry process bears significance to the mode of fine grinding of raw materials and of blending them, mixed with water or as dried materials. It will be seen later how the wet or dry method determines certain elements of an installation with which the electrical engineer may be concerned.

Limestone arrives at the cement plant where it is crushed in a primary crusher. This crusher may be

Two four-support, two-roller type kilns, one with an enlarged calcination zone, and two coolers in an eastern cement plant.

a gyratory, jaw, or roll type, whichever type is best suited to the operating requirements. The product of the primary crusher is again crushed in a secondary breaker, which is usually a hammer mill. In the secondary crusher the stone is reduced so that all of it will pass through a screen having 1 in. square holes.

A wash mill, which consists of a brick-lined octagonal pit in which revolve harrows of rakes, prepares the clay, the other raw material, in the form of a digested homogeneous mud containing about 60 percent water. Then, chemical control having been established over the raw materials, they are proportioned roughly and fed to the raw grinding mill, a revolving cylinder filled with metallic balls or slugs. In this mill the limestone and clay are finely comminuted and mixed and emerge as a fluid pulp or slurry with water content from 32-40 percent by weight.

This slurry is pumped into concrete tanks equipped with agitator mechanisms, wherein its composition is corrected and made suitable for subsequent burning by blending the slurry from two or more of the blending tanks. Thus, the blended slurry contains about 76 percent calcium carbonate and 24 percent of argillaceous materials in correct proportions based upon the dry weight of the raw material required to burn one barrel of clinker. In addition to the dry weight, the slurry includes water within the limits stated previously.

The burning operation

An average size, modern, wet process, rotary kiln, in which the raw materials are burned to form clinker, is a long steel cylinder about 8½ ft in diameter and 300 ft long, rotating on its axis at the rate of 1.2 rpm. Its axis is inclined at an angle of approximately 7/16 in. to the foot so that the materials fed in at the upper end travel slowly to the discharge end. The kiln is lined along its entire length with refractory bricks and is supported by several carrying mechanisms having two rollers each, upon which revolve the kiln tires or riding rings.

A system of dense curtains of chains is installed in the feed end of the kiln to assist in the transfer of heat in the combustion gases to the slurry. Filters

This 35 ft long, dry grinding, compartment mill, exemplifying single-stage grinding, is equipped with air separation.

may be used to reduce the water content of the raw slurry (in the wet process) before it is fed to the kiln, thus permitting the use of a shorter kiln; but the chains are omitted if filters are used.

Dry process kilns are not equipped with chains because the raw materials enter the kiln in a dry state, and there is not the problem of evaporation of large amounts of water. Efficient operation of dry process kilns is now achieved by building them comparatively long, which permits increased heat transfer with a corresponding lowering of the temperature of the exit gases.

A large part of the heat carried out by the kiln combustion gases where the exit temperature is high is, in some cases, recovered and used to generate steam to drive turbo-alternators for power generation. Cement plants of this type are called "waste heat" cement plants, and they may employ either the wet or dry process.

Twenty years or more ago waste heat recovery was given important consideration in the design of new cement plants, and there are now many successful plants in the United States which use waste heat recuperation. Concurrent with the greater development and extension of power networks and the perfection of the long wet process kiln equipped with auxiliary apparatus and control to provide high thermal efficiency, waste heat installations are given less consideration than in the past. Obviously, with the high thermal efficiency of the long wet process kiln from which gases leave the kiln at low temperature, waste heat recuperation cannot be used.

Continuing with the outline of the wet process involving the 8½ ft by 300 ft kiln described previously, the waste gases from that kiln, including the water vapor, will be reduced to approximately 400 F. A large part of the water is driven off as the material passes through the chain system. The partly dried material is then dried completely farther down the kiln, preheated, calcined, and when it reaches the hottest — or burning — zone of the kiln, hard granular masses, greenish black in color, ranging generally in size from ⅛ in. to 1 in. in diameter, are formed. This product — clinker — has no cementitious properties *per se* but must be ground to a very fine powder in order to make effective its latent hydraulic properties.

The fuel, which supplies heat for the chemical and physical processes which accompany the formation of clinker, may be pulverized coal, fuel oil, by-product coke oven gas, or natural gas injected by suitable burning apparatus into the discharge end of the kiln. The lower 25 to 30 ft of the kiln is called the combustion or burning zone, and the fuel is burned within it with from 25 to 30 percent of injected primary air. The remainder of the air required for combustion — the secondary air — is preheated in the clinker cooler.

Control

An exhaust fan at the feed end of the kiln provides sufficient draft to withdraw the kiln gases and discharge them through a stack. The kiln feeder is synchronized electrically with the speed of the kiln and delivers a desired amount of feed at all times. The kiln operator is enabled, by means of indicating and recording gauges and automatic electrical controls contained in a specially designed switchboard panel, to maintain conditions required for the most efficient expenditures of fuel for clinker production. From 1,000,000 to 1,100,000 Btu would ordinarily be required to produce 365 lb of cement clinker in a modern kiln equipped with a heat recuperating chain system and all the modern appurtenances. For the dry process, with a modern long kiln, about 950,000 Btu per bbl would be required, including the fuel necessary to dry the raw materials before they are ground for kiln feed.

The clinker leaves the kiln at approximately 2200 F and must be cooled before it can be handled by cranes or conveyors and delivered to a storage yard or to the clinker grinding mill. Rapid chilling of clinker makes it easier to grind and imparts desirable qualities to the resultant cement. The older form of clinker cooler consists of a tubular cylinder through which the clinker, as it passes, is showered through a countercurrent flow of air induced by the stack effect of the kiln and exhaust chimney. More modern are the air quenching clinker coolers of the grate type, in which air is forced through a bed of clinker on a grate which conveys the clinker forward. The air used to cool the clinker becomes highly heated and is used for secondary combustion of air in the kiln. About 75 percent of the sensible heat in the clinker is returned to the kiln in the preheated air.

Cooled clinker is delivered to a storage yard, one section of which is generally reserved for the clinker and others for the raw materials—limestone and clay. An overhead traveling crane may serve the storage building, filling the grinding mill bins and transporting materials according to needs.

Finish grinding

Clinker grinding may be accomplished in a mill similar in construction to the raw grinding mill except that clinker necessarily is ground dry. Modern clinker grinding departments, which may have to meet specifications for the five types of portland cement designated by the American Society for Testing Materials, have incorporated refinements into their grinding circuits which enable a quick change-over to be made in grinding each of the several varieties of cement. Air separators classify the ground cement and return oversize material for regrinding. The exhaust fan of the dust collector cools the interior of the mill by inducing a current of air to flow through the grinding chambers, thus preventing the leakage of objectionable dust into the mill building.

To retard the setting time, two and one-half to three percent of gypsum is added to the clinker before it is ground in the mill.

Finished cement is transported to storage silos by a pneumatic conveying system or by elevators and screw conveyors. Another conveying system circulates the cement within the silos in order to overcome any variations in the product and also delivers cement to the packing machines. The latter are semi-automatic and inject a constant weight of cement into the cloth or paper sacks, which are automatically released and sealed when filled. Cement is also shipped in bulk in box cars or trucks for large projects.

IT'S A DARK SECRET

Most of us know little about carbon black except that it's black. Penetrating the smudge, its role in modern warfare ranges from increasing fourfold the tire life of "jeeps" and mobile artillery to making opaque paints for blackout protection.

A. R. Tofte

ADVERTISING DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

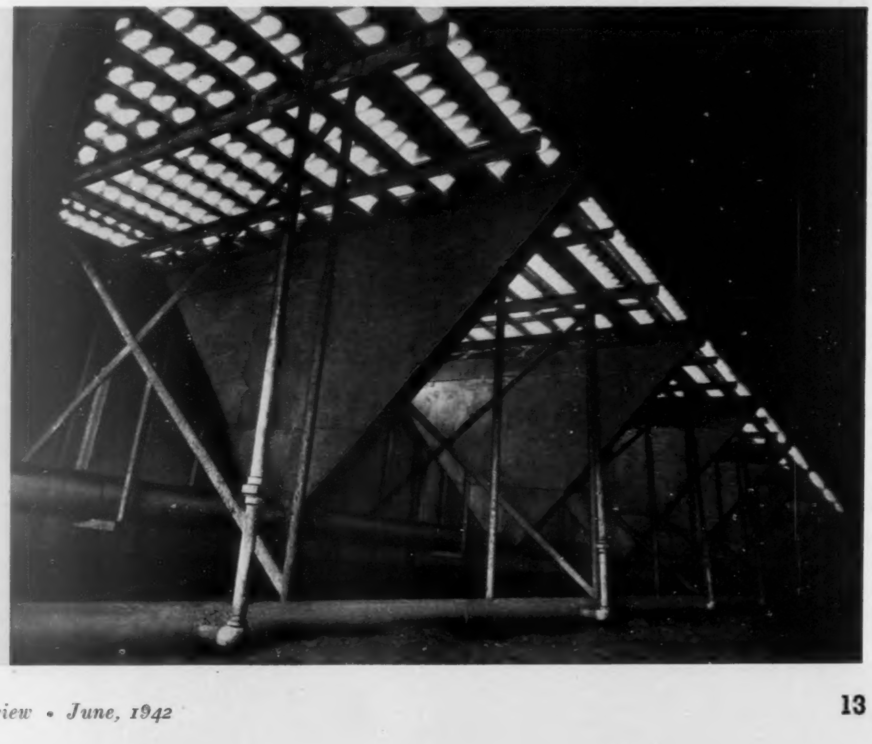
Yes, it's a dark secret about carbon black . . .

For instance, every electrical man knows that rubber is a good electrical *insulation* material. And yet—if you mix the right formula of carbon black with the rubber, you can obtain almost any degree of *conductivity* you want. Rubber manufacturers for years have been working on this principle, discovering new and important uses for carbon black in the electrical industry, rubber tire manufacture, and in other fields. In many companies, carbon black formulas are among their most closely guarded trade secrets.

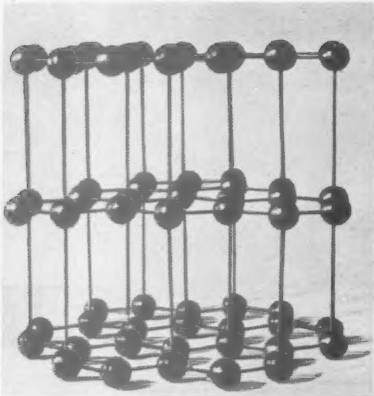
But that's not all there is to carbon black. Let's go back in time about forty years and pay a visit to your grandmother —

Like, yet unlike, lamp soot

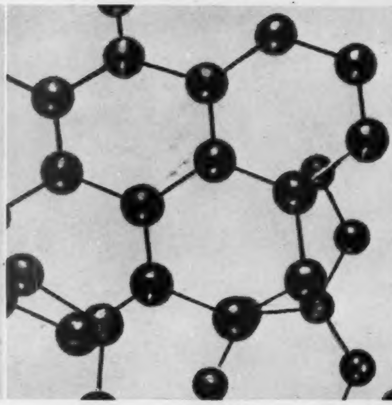
You probably would feel a little sorry for her, as she struggles at tasks that do not exist for the housewife of today. One of those tasks would most certainly be the cleaning of soot from the kerosene lamp chimney. Oddly enough, the soot she cleaned off the glass chimney was the precursor of today's carbon black. There are differences between the two, but fundamentally they belong to the same family.



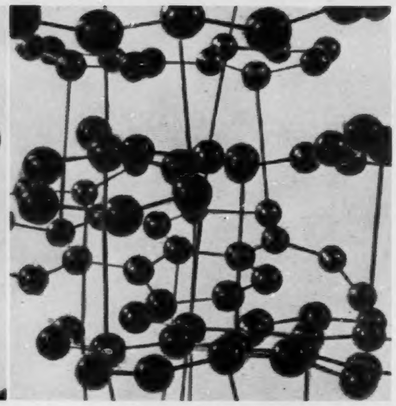
Tiny gas flames each impinge about one ounce of carbon black a day on moving channels. By having literally millions of these flames, enough carbon black is obtained for commercial needs.



Graphite atoms are orderly arranged in three dimensions in the crystal.



Carbon black atoms are arranged systematically in two directions . . .



. . . but present a helter-skelter appearance in the third direction.

Let's put it this way —

Soot from a kerosene lamp is a carbon product of the free flame and is comparable to commercial lampblack. Lampblack, to differentiate, is the soot produced from a large free flame resulting from the burning of liquid oils or tars. Thus, kerosene lamp soot and lampblack soot are similar in that liquid hydro-carbons are used as fuel and the soot comes from a free flame. A difference exists in the size of the flame; for, in making commercial lampblack, some of the pots in which the liquids are burned are as much as four feet in diameter.

In comparing lampblack or chimney soot with carbon black, there are several interesting differences. Instead of being the product of a liquid oil or tar flame, carbon black is the product of burning natural gas. Probably the most important factor that distinguishes carbon black from the soot of the lamp chimney or lampblack pot is that carbon black is an impingement black. The flame actually licks or impinges upon the under side of some metal, usually channel iron. Of course, another big difference is that lampblack is of minor commercial importance; whereas carbon black is a product with wide commercial use and extensive development possibilities.

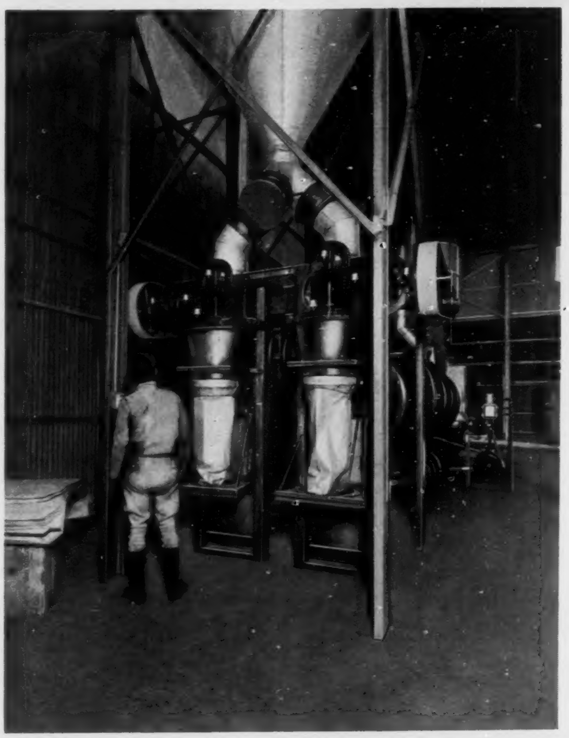
Flame method still used

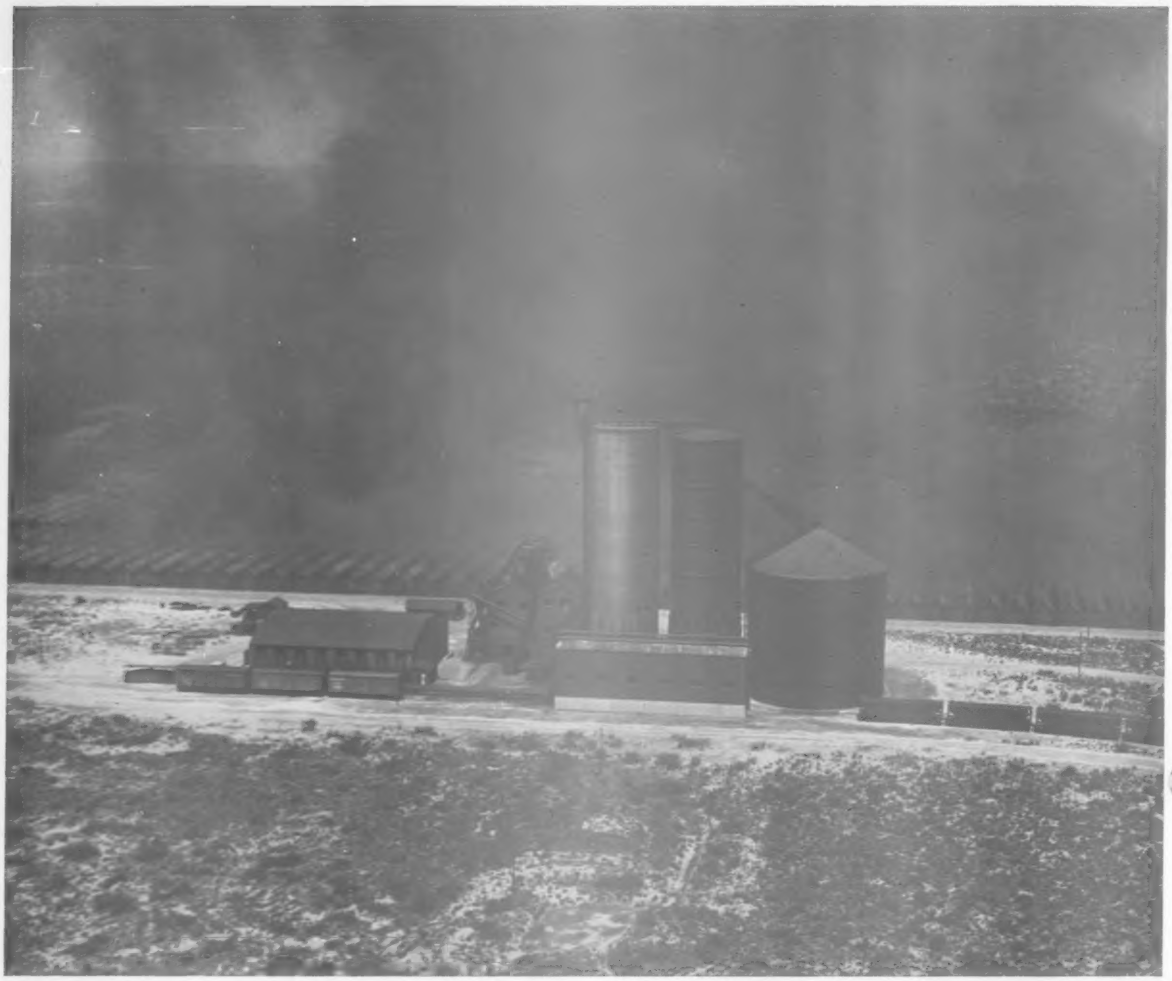
It might have been expected that engineering skill by now would have found some way to improve on the flame method of making carbon black. Your grandmother made soap, too, but science has found ways of making soap on a big scale, thousands of pounds at a time. But not in the case of carbon black —

In fact, if grandma had wanted to "smoke up" her lamp, she could probably have collected about an ounce of soot on her chimney in a day's time. Today, in the carbon black industry, that is still about all the material that can be obtained from each of the tiny gas

AT LEFT: Where temperatures hover around 180 F above ambient and carbon black fills the air at all times, these totally-enclosed fan-cooled motors move the carbon black to the processing rooms.

Fine enough to pass 300-mesh screen, carbon black is well sacked before shipping to rubber tire manufacturers, lacquer makers, and other users.





Dense clouds of smudge arise from this west Texas carbon black plant — reason enough for its location away from any town.

flames. It is only by multiplying the number of flames that sufficiently large quantities can be produced.

There's another interesting fact about carbon black. Unlike graphite atoms, which are arranged in orderly fashion in all three dimensions, carbon black atoms are systematically arranged in only two planes. In the third plane they are completely disordered, and this peculiar fact is the reason for the many important uses to which we put carbon black.

Plants located at natural gas source

Because it takes a lot of low-cost fuel to operate the millions of tiny flames, most carbon black plants today are located in the area in or near the Texas Panhandle, where natural gas is both abundant and cheap. In 1939, for instance, carbon black plants used 347 billion cubic feet of gas, or about 14 percent of all marketable natural gas in the country.

Manufacturing problems in the Panhandle, however, entail numerous complications. Weather is subject to great changes. Winter brings rain and snow; spring presents numerous dust storms; the summer is long and hot. In the alleyways between the hothouses, temperatures are around 180 F above the ambient at all times. Motor service requirements in these alleyways are probably as severe as any in all industry. For example —

In moving the carbon black to the processing room, motors operate continuously 24 hours a day, all year long. They go full speed in one direction. When they reach the end of the travel, without any time delay the pilot circuit is reversed through a single-pole, double-throw reversing switch, and the motors operate in the opposite direction for a like period.

Working under carbon black conditions is in itself a severe handicap, for carbon black will pass a 300-

mesh screen and has a high degree of conductivity. This necessitates the use of totally-enclosed, fan-cooled motors, with housing seal, bearing seal, narrow smooth air passages, extra-heavy insulation, and with tightly sealed conduit terminal boxes.

Stringent standards set up

There are about ten companies in the country making the great bulk of commercial carbon black. Processing, in the last decade, has become more complicated with each new use to which it is applied. In order to make black that will answer specifications of increasing exactness, manufacturers themselves have set up stringent standards for grit, moisture, acetone extract, ash, and rate of cure. Literally hundreds of millions of pounds of carefully graded carbon black are shipped each year for use all through industry.

In rubber tires, for example, carbon black plays an extremely important role. Roughly 3½ pounds of black are used in each tire. Mixed in the ratio of one part black to two parts rubber, the resultant wearing qualities are more than four times that of rubber alone. Carbon black also finds important uses in providing the correct jet lustre to paint, lacquers, printing inks, and many other products.

In the electrical industry, the use of carbon black is quickly assuming great importance. For, although rubber has always been considered a good insulating material, the addition of the right kind of carbon black can give it high conductivity qualities.

Static electricity, even in minute amounts, is often a danger in the presence of highly volatile motor fuels, anesthetics, and chemical solvents. Further, the discharge of static electricity may effect rubber stock deterioration.

By using carbon black in the rubber, a way is found to dissipate static electricity and guard against these dangers. In fact, it is possible to achieve either a high insulation value or a high degree of conductivity, depending wholly on proper selection of carbon black from the many grades commercially available. Natural rubber has an electrical resistance of 10^{15} ohm-cms, or 1600 billion times that of rubber loaded with forty to forty-five parts carbon black of a special conductive type.

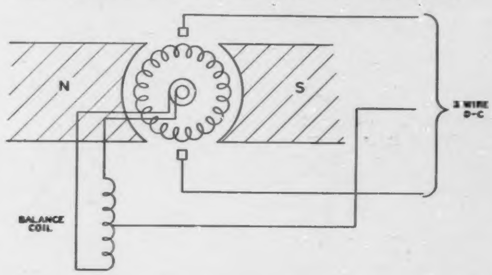
In other words, if it weren't for carbon black, your auto tires would be giving you a scant few thousand miles of wear when all of us are trying to get maximum mileage out of every tire. And also, if it weren't for the electrical conductivity of the carbon black in your tires, you might have difficulty operating your car radio, for it is through the tires that ground is made.

To the electrical man, carbon black offers many new opportunities for using rubber when conductivity instead of insulation is desired.

WHAT'S THE ANSWER?

Question—How is it possible to have a three-wire direct-current generator with two slip rings?—J. W.

Answer—The slip rings of a three-wire generator transfer the alternating current from the armature winding to an external balance coil from which a neutral is taken for the d-c circuit. Any number of phases could be tapped from the armature winding; but single-phase, three-phase, and four-wire two-phase are the most common. Economics determine the best way for getting the neutral out of the generator. A single-phase balance coil is heavier and more expensive than a three-phase balance coil, but the former requires two slip rings instead of three on the generator, which reduces the overall length.



Two-ring three-wire generator.

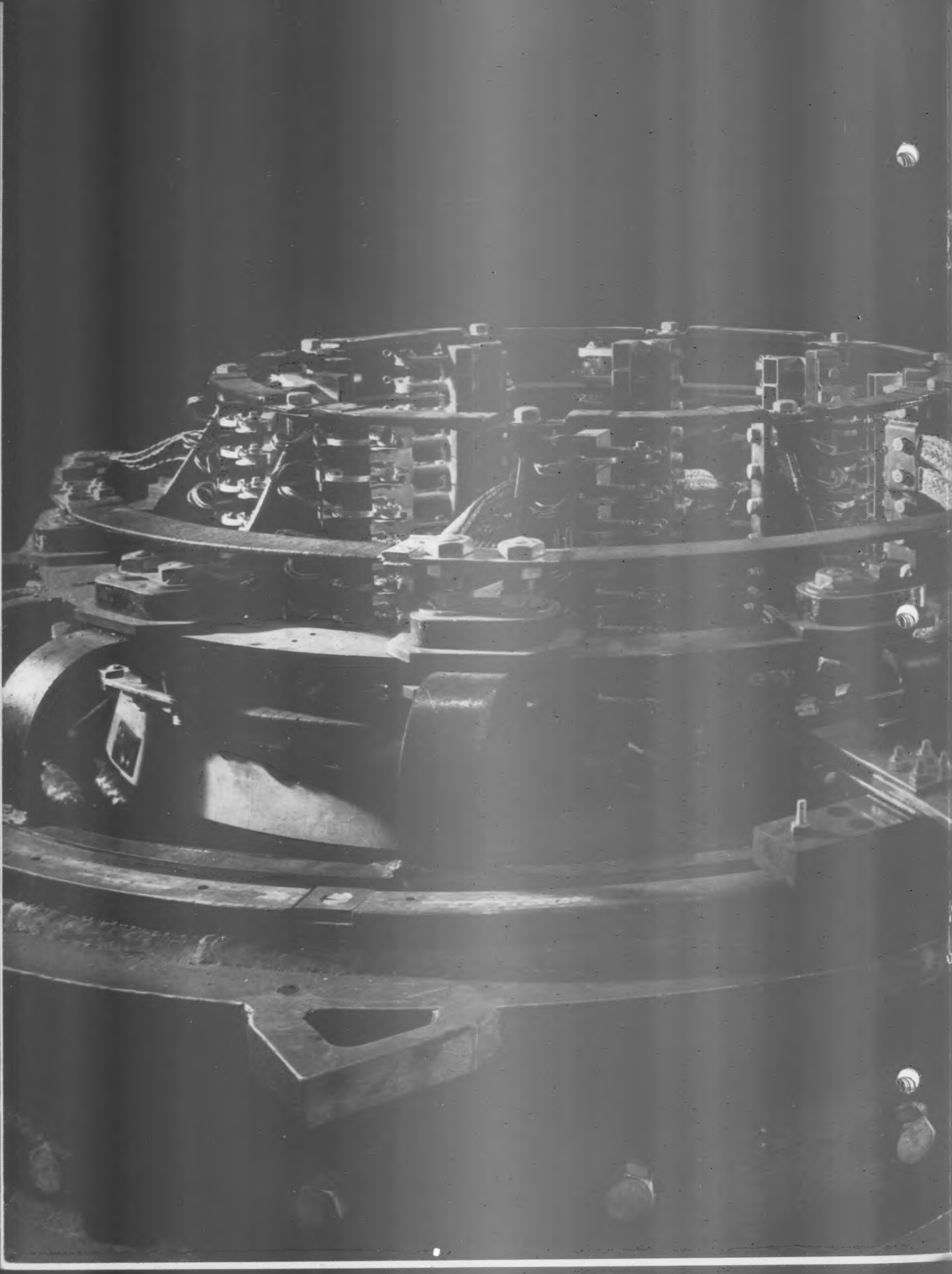
Question—Do "spill gaps" on bushings provide adequate protection for a transformer against lightning?—P. M. S.

Answer—This question cannot be given a single concise answer. Many factors influence each particular installation. First an economic qualification of the term "adequate protection" must be made. This must include the cost of interruptions that may be caused by switching surges flashing over a "short" spill gap.

Any protection a spill gap offers depends on the correlation of these more important factors: volt-time characteristic of the gap, volt-time characteristic of the transformer insulation, the impedance to ground offered to the surge by the transformer, the steepness of the front of the voltage wave and the rate of decay of the voltage wave.

"What's the Answer?" is conducted for the benefit of readers of ELECTRICAL REVIEW who have questions on central station, industrial or power plant equipment. Send all questions to the Editors of ELECTRICAL REVIEW.

ON FOLLOWING PAGES: Twenty-four hours a day, seven days a week, production is speeded on the assembly of these d-c generator yokes. Rated 1200 kw, 750 rpm, 550 volts, they will be used on 12,000 shp diesel-electric drives aboard naval auxiliaries.



"SLUGGED ARC"

How vertical is a vertical generator shaft? Such shafts don't "jest grow" vertical. It takes pains and no little ingenuity to ascertain that they are straight and truly aligned.

H. A. Wallace

SERVICE AND ERECTION DEPARTMENT • ALLIS-CHALMERS MANUFACTURING COMPANY

During the last decade many remarkable improvements in machine tools have made possible the machining of equipment to far greater accuracy limits than ever before. Consequently, in order to take the fullest advantage of these advances, it becomes necessary to exercise greater care and to use more exact methods in installing precision-manufactured equipment.

Years ago, spirit levels and long straight-edges were used in setting equipment; today, to do the same job, we use micrometer targets and precision engineer's levels which are accurate to 0.0005 in. It was formerly common practice to tighten coupling bolts by "ring" or "feel," but it has been proved that a possible variation of 500 percent might exist in the unit stresses in the bolts, even when tightened by the most careful and experienced sledge hammer artists. Today, uniform unit stresses in coupling bolts are assured by measurement of the stretch or elongation of the bolts to 0.001 in.

For years, on vertical machines with large adjustable shoe thrust bearings, the adjustment of these shoes for uniform loading has been by "feel." The relative inaccuracy of this method has been emphasized in the last few years by the introduction of the ingenious but comparatively simple "slugged arc" method of accurately equalizing the loading of thrust bearing shoes. This is not to disparage the installation work done by the so-called "oldtimers." Thousands of machines, erected by men of the old school, have given satisfactory service for long periods of time. They did a fine job, considering the tools with which they had to work. But recent improvements in installation accuracy warrant an explanation of the most modern methods of obtaining precise shaft alignment and bearing adjustment on vertical rotating machinery — especially waterwheel driven generators.

In aligning the shaft of a vertical machine, it is of the utmost importance that the thrust bearing shoes be uniformly loaded when the shaft is plumb. The most modern and exact procedure for obtaining this condition of loading is the "slugged arc" method, an explanation of which follows.

Procedure

First, the shoes are adjusted roughly by "feel," being sure that each shoe is carrying some load (the amount is immaterial). The shaft should be approximately plumb but need not be accurately so. Fig. 1 shows the procedure and the tools required.

The "slugged arc" is the distance from point A to point B measured along arc of radius R. After all the screws have been tightened by sledge hammer until each is carrying some of the load, the following procedure is carried out on each screw, one at a time. The hand calibrating wrench D is placed on the head of the adjusting screw, and point A is obtained by scribing a mark along edge C. Wrench D is then removed, and the screw loosened completely. Wrench D is again placed on the head of the screw, being certain that it contacts the same flats of the screw head as it did originally when locating point A. The screw is then tightened by the hand calibrating wrench several times, each time scribing a mark along edge C. Care should be taken to use the same amount of pull each time when tightening with hand calibrating wrench D.

The result will be a series of lines closely grouped. An average of these lines is estimated, and a single line determines point B. Measuring with the graduated arc scale E from point A to point B along arc of radius R, the slugged arc for that particular screw is determined and recorded. The screw is then tightened with a wrench and sledge hammer to its original

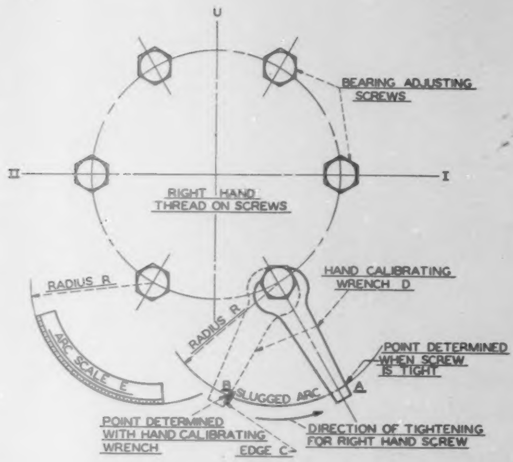


Fig. 1

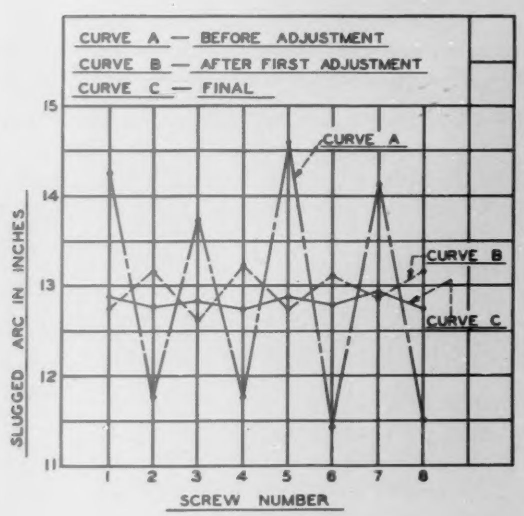


Fig. 2

position A. The same procedure is then followed for each successive screw. It is important that the same man do the hand tightening with wrench D for a complete round so that approximately the same force will have been applied on each screw. After all the screws have been checked, their respective slugged arcs are plotted, as shown in Fig. 2, and will approximate curve A of this figure.

It is obvious that screws number 1, 3, 5, and 7 are too tight and that screws 2, 4, 6, and 8 are not tight enough. The screws that are too tight are loosened a little, and the ones that are not tight enough are tightened a little. Another check of the slugged arc for each screw is made, and the values, plotted on the same graph with curve A, form curve B, Fig. 2. A study of curve B shows that the adjustments made have been excessive. Screws number 2, 4, 6, and 8 are then loosened a very small amount; likewise, screws number 1, 3, 5, and 7 are tightened a very small amount. A final check of the slugged arcs will approximate a curve such as curve C, which is satisfactory and guarantees a very accurate distribution of load on the bearing shoes. After a few trials, the ability to estimate the correct amount of adjustment will be developed, and a bearing can be accurately adjusted in two or three trials at the most.

In order to facilitate the aligning of the shaft, a further explanation of Fig. 1 is necessary. There is a definite relationship between radius R, the circular pitch of the adjusting screw, and the amount of room between the bearing proper and the walls of the bearing housing. Of course, the radius should be small enough to allow free movement of the hand calibrating wrench along the arc. To plumb or align the shaft it will be necessary to change the position of some or all of the adjusting screws without changing the distribution of load on the shoes. If the proper radius of arc is used, there will be a certain definite relationship between the amount of movement, up or down, of the screw for a corresponding change in arc, which will aid in the adjustment.

Example

For example: Assume that the circular pitch of the screw is ⅛ in. This means that the screw will raise or lower ⅛ in. for each rotation of the screw through 360 deg. If radius R is set at 20 in., then every inch of arc represents 0.001 in. change in the height of the adjusting screw. It is important to know what the change in the height of the screw will be for a given change in arc when plumbing the shaft. Choosing a radius R which will give an even dimension of arc for every 0.001 in. movement of the screw will greatly facilitate the calculations and adjustments. An approximate formula to use, when deciding on radius R, is shown below:

$$R = \frac{XP}{.0063}$$

where R = Radius of slugged arc

X = Arc change for every 0.001 in. change in screw elevation

P = Circular pitch of screw.

By trial, the best value for radius R can be obtained to suit any local condition.

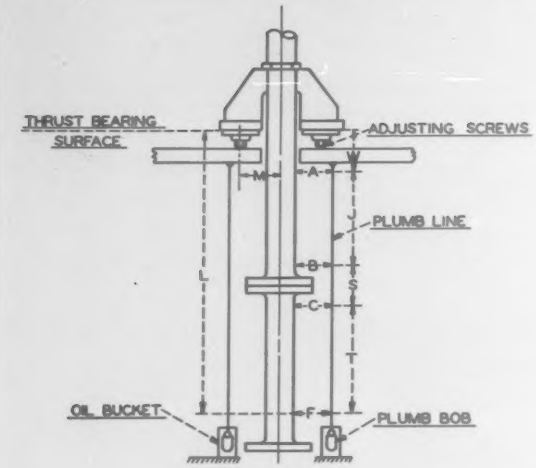


Fig. 3

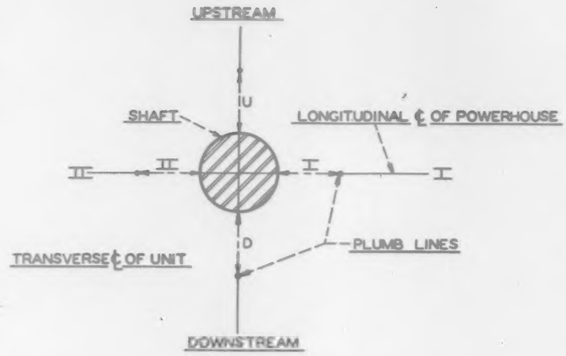


Fig. 4

"Plumbing" the shaft

By "plumbing" a shaft is meant the placing of that shaft in a true vertical position. This is accomplished by raising and lowering the proper adjusting screws of the thrust bearing. The checking of the actual vertical position of the shaft is done with plumb lines as illustrated by Fig. 3.

There should be four plumb lines located around the shaft 90 deg apart. The calculations will be simplified if the lines are set on, or as near as practical to, the longitudinal and transverse centerlines of the machine. The plumb lines should be steel piano wire of approximately 0.020 in. diam. On the end of each wire is suspended a plumb bob of such weight as to guarantee a taut wire. The bobs are suspended in heavy oil to dampen pendulum action. It is not necessary for all the wires to be the same distance from the shaft, but it is more convenient if they are.

The first check to be made is to determine whether or not the shaft is straight. This is done by taking readings from the shaft to each of the four wires at the elevations A, B, C, and F, shown on Fig. 3. Now, (1) if the shaft is perfectly straight and the same diameter throughout its length, and (2) if the shaft is plumb and the plumb wires are all the same distance from the shaft at elevation A (Fig. 3), then all the readings will be identical. This, of course, is an almost impossible condition without making some adjustments. Then, too, the shaft will rarely, if ever, be the same size throughout its length because of bearing journal surfaces, couplings, and variations in machining. This will make no difference in the result as will be shown later.

The analysis of the plumb line readings is as follows: Fig. 4 shows the location of the plumb wires with respect to the center lines of the machine and also gives the designations of the readings.

The I-II line is always the longitudinal centerline of the powerhouse, and the Upstream-Downstream line is the transverse centerline of the unit. The readings are thus designated as I, D, II, and U, depending on the direction in which they are measured from the shaft. Since the wires hang plumb and the shaft is approximately vertical, the above holds true throughout the length of the shaft. The only assumption to be made is that the shaft is round.

Example

To check the straightness of the shaft, readings are taken on all four wires, at each of the four elevations A, B, C, and F. Table 1 shows some actual readings which will be analyzed and explained. For this example, the following dimensions have been assumed for Fig. 3:

W= 4 ft	S= 4 ft	L=24 ft
J= 8 ft	T= 8 ft	M= 2 ft

An analysis of the data in Table 1 shows that the shaft is straight, out of plumb 0.005 in. toward I in 20 ft (Column 4), and 0.010 in. out of plumb toward U in 20 ft (Column 9). Since the thrust bearing surface is the pivot point for plumbing the shaft, an extrapolation must be made to give the corrected "out-of-plumbness" for the full length of shaft. This is shown to be 0.006 in. toward I and 0.012 in. toward U. The straightness of the shaft is shown by the fact that the amount of the "out-of-plumbness" at each of

	1	2	3	4	5	6	7	8	9	10
Elev.	I	II	Difference Between I and II	Out of Plumb	Out of Plumb (Corrected)	U	D	Difference Between U and D	Out of Plumb	Out of Plumb (Corrected)
Thrust Bearing Surface	....	....	....	....	.000	....	....	....	....	.000
A	15.342	15.571	.229	.000	.001 → I	16.668	17.820	1.152	.000	.002 → U
B	15.320	15.553	.233	.002 → I	.003 → I	16.644	17.804	1.160	.004 → U	.006 → U
C	15.339	15.574	.235	.003 → I	.004 → I	16.662	17.826	1.164	.006 → U	.008 → U
F	15.327	15.566	.239	.005 → I	.006 → I	16.648	17.820	1.172	.010 → U	.012 → U

Table 1

the four elevations is directly proportional to the distance from the thrust bearing surface. Columns 1 and 2 show that the shaft is 0.040 in. larger in diameter at B than it is at A, and 0.020 in. larger at F than it is at A. The diameter of shaft at A and C is the same.

In order to place this shaft in a true vertical position, it is necessary to move it 0.006 in. toward II at F and 0.012 in. toward D at F. The distance M from the center of the shaft to the center of the adjusting screws is 2 ft. The shaft is 24 ft long. The raising of one of the thrust shoes a given amount and the lowering of the corresponding shoe diametrically opposite, the same amount, will give a movement of the shaft, at F, 12 times as great since the ratio is 2 to 24. When moving the bottom of the shaft toward either I or II, the pivoting takes place along the Upstream-Downstream centerline. When moving the bottom of the shaft towards either U or D, the pivoting takes place along the I-II centerline. As stated above, the pivoting is accomplished by raising a shoe a certain amount and lowering the corresponding shoe diametrically opposite, the same amount. This raising and lowering does not alter the adjustment of the uniform loading of the shoes.

Figure 5 shows a four-shoe bearing with the shoes not located on the centerline of the unit. In order to move the shaft 0.006 in. toward II at F (Fig. 3), it will be necessary to raise shoes No. 1 and No. 4 a certain amount and lower shoes No. 2 and No. 3 the same amount. The calculation of this amount of shoe movement and its equivalent in slugged arc increment X is shown below:

$$X = \frac{SV}{.001R} \cos \beta$$

where X = Required change of "slugged arc"

S = Amount of shaft movement required at F (Fig. 3)

R = Ratio L/M (Fig. 3)

V = Arc change in inches per .001 in. screw movement

β = Angle location of shoes (Fig. 5).

To move 0.006 in. toward II at F (Fig. 3)

$$X = \frac{.006 \times 1}{.001 \times 12} \times .707 = .354 \text{ in. (approx. 23/64 in.)}$$

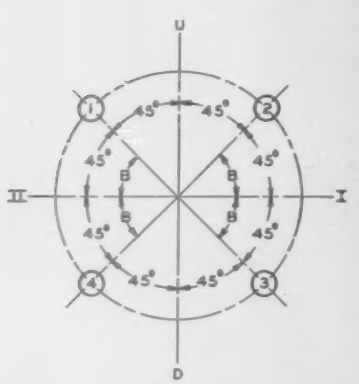


Fig. 5

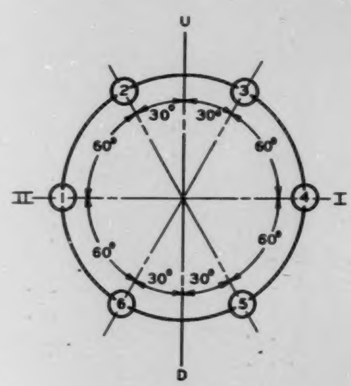


Fig. 6

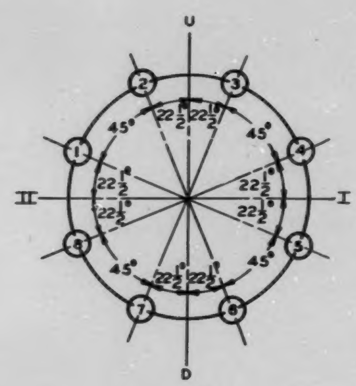


Fig. 7

Result:

Screw No.	Direction of Movement	Amt. of Movement
1	Raise	.354 in.
2	Lower	.354 in.
3	Lower	.354 in.
4	Raise	.354 in.

The same procedure is followed to move the shaft 0.012 in. toward D at F (Fig. 3).

$$X=\frac{.012\times 1}{.001\times 12}\times .707=.707 \text{ in. (approx. 23/32 in.)}$$

Result:

Screw No.	Direction of Movement	Amt. of Movement
1	Lower	.707 in.
2	Lower	.707 in.
3	Raise	.707 in.
4	Raise	.707 in.

These adjustments may be made separately by moving shaft toward II and then moving it toward D. However, it is much more economical, from the standpoint of labor and time, to make the two sets of adjustments simultaneously. This is done by combining, algebraically, the two adjustments on each screw into one adjustment. This is shown in Table 2.

Screw No.	To Move .006 in. Toward II	To Move .012 in. Toward D	Combined Adjustment		
			Direction	Decimal	Approx. Scale
1	Raise .354 in.	Lower .707 in.	Lower	.354 in.	$\frac{23}{64}$ in.
2	Lower .354 in.	Lower .707 in.	Lower	1.061 in.	$1\frac{1}{16}$ in.
3	Lower .354 in.	Raise .707 in.	Raise	.354 in.	$\frac{23}{64}$ in.
4	Raise .354 in.	Raise .707 in.	Raise	1.061 in.	$1\frac{1}{16}$ in.

Table 2

Six-shoe bearing

The same procedure is followed for adjustment of a six-shoe bearing shown in Fig. 6, or an eight-shoe bearing shown in Fig. 7. The important thing to remember is that the formula

$$X=\frac{SV}{.001R}\cos\beta$$

must be applied for each combination of shoes which are the same distance from the centerline about which the rotation takes place. The fundamental part of this formula is

$$X=\frac{SV}{.001R}$$

which gives the correct value for the shoe which is at a distance M (Fig. 3) from the pivot axis about which the shaft is being adjusted. The value of $\cos\beta$ merely takes care of the decrease in necessary adjustment for the shoes which are a distance less than M from the pivot axis. In other words, when a shoe is distance M from the pivot axis,

$$\cos\beta=1$$

For any distance less than M from the pivot axis $\cos\beta$ has some value less than one. In Fig. 6, when U-D is the pivot axis, the value of β for shoes No. 1 and No. 4 is zero and $\cos\beta=1$. For shoes No. 2, 3, 5, and 6, $\beta=60$ deg and $\cos\beta=0.500$. In this same figure, when the pivot axis is I-II, $\beta=90$ deg for shoes No. 1 and 4, and $\cos\beta=0$. This means that these two shoes have no adjustment because they are on the pivot axis. Using the same pivot axis (I-II) the value of β is 30 deg, and $\cos\beta=0.866$. Table 3 shows the necessary adjustments for a six-shoe bearing when moving 0.006 in. toward II and 0.012 in. toward D at F (Fig. 3).

Screw No.	To Move .006 in. Toward II	To Move .012 in. Toward D	Combined Adjustment		
			Direction	Decimal	Approx. Scale
1	Raise .500 in.	Zero	Raise	.500 in.	½ in.
2	Raise .250 in.	Lower .866 in.	Lower	.616 in.	$\frac{39}{64}$ in.
3	Lower .250 in.	Lower .866 in.	Lower	1.116 in.	$1\frac{7}{64}$ in.
4	Lower .500 in.	Zero	Lower	.500 in.	½ in.
5	Lower .250 in.	Raise .866 in.	Raise	.616 in.	$\frac{39}{64}$ in.
6	Raise .250 in.	Raise .866 in.	Raise	1.116 in.	$1\frac{7}{64}$ in.

Table 3

Eight-shoe bearing

The same procedure is followed for an eight-shoe bearing (Fig. 7) as for a six-shoe bearing. With pivot axis U-D (Fig. 7), the value of β for shoes No. 1, 4, 5, and 8 is 22½ deg. For shoes No. 2, 3, 6, and 7, $\beta=67\frac{1}{2}$ deg. With I-II (Fig. 7) as the pivot axis, the value of β for shoes No. 2, 3, 6, and 7 is 22½ deg and for shoes No. 1, 4, 5, and 8, $\beta=67\frac{1}{2}$ deg. Table 4 shows the necessary adjustments for an eight-shoe bearing when moving 0.006 in. toward II and 0.012 in. toward D, at F (Fig. 3).

Screw No.	To Move .006 in. Toward II	To Move .012 in. Toward D	Combined Adjustment		
			Direction	Decimal	Approx. Scale
1	Raise .461 in.	Lower .383 in.	Raise	.078 in.	$\frac{5}{64}$ in.
2	Raise .192 in.	Lower .922 in.	Lower	.730 in.	$\frac{47}{64}$ in.
3	Lower .192 in.	Lower .922 in.	Lower	1.114 in.	$1\frac{7}{64}$ in.
4	Lower .461 in.	Lower .383 in.	Lower	.844 in.	$\frac{27}{32}$ in.
5	Lower .461 in.	Raise .383 in.	Lower	.078 in.	$\frac{5}{64}$ in.
6	Lower .192 in.	Raise .922 in.	Raise	.730 in.	$\frac{47}{64}$ in.
7	Raise .192 in.	Raise .922 in.	Raise	1.114 in.	$1\frac{7}{64}$ in.
8	Raise .461 in.	Raise .383 in.	Raise	.844 in.	$\frac{27}{32}$ in.

Table 4

AT LEFT: Illustrating the greater accuracy now possible in machining large forgings is this shaft being checked in a lathe. And, because of refinements in manufacture, new methods of precise alignment have been developed for the field erection of large machines.

The application of formula

$$X = \frac{SV}{.001R} \cos \beta$$

can be used on any adjustable thrust bearing regardless of the number of shoes.

When the shaft has been moved by the amount calculated from the first plumb-line check, another check should be made to see if the shaft is actually plumb. After the shaft has once been proved straight, it is necessary to take readings only at elevations A and F (Fig. 3) when checking for plumbness.

Completing the alignment

The one remaining check to be made to complete the alignment is to prove the thrust bearing runner surface perpendicular to the centerline of the shaft. This can be done by making a shaft rotation check. The turbine and generator guide bearings are removed so that the shaft will hang freely suspended on the thrust bearing. The shaft is already in a true vertical position after the adjustments described above.

There are two satisfactory methods of making these measurements. One is with plumb lines, and the other is to check the eccentric movement of the shaft, top and bottom, by means of reference points or dial indicators, when it is rotated 360 deg.

If the shaft is not perpendicular to the thrust bearing surface, the bottom of the shaft will travel in a circle. The diameter of that circle is called the "shaft throw." The shaft throw is determined by taking zero readings with the shaft plumb and central with respect to the unit centerlines. The shaft is then rotated 90 deg, and the same measurements taken. This is repeated in 90 deg increments until one complete rotation is made.

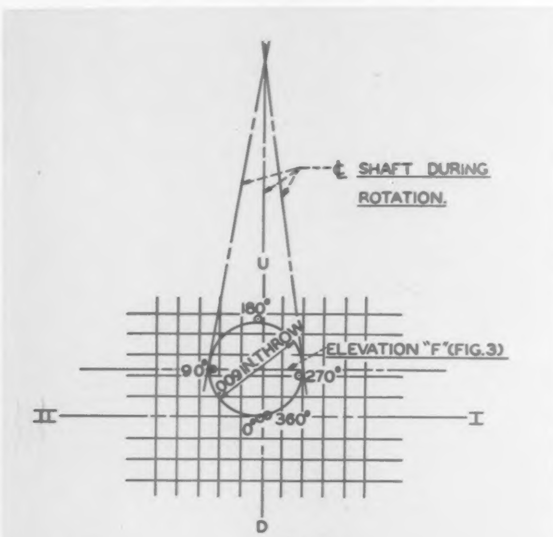


Fig. 8

The amount of throw is then determined by plotting the points which represent the center of the shaft for each of the positions of rotation—0, 90, 180, 270, and 360 deg. A circle is then drawn through the five points, and the diameter of that circle represents the amount of shaft throw. Fig. 8 illustrates the above based on the setup in Fig. 3. It shows a throw of 0.009 in. at elevation F (Fig. 3). This is a very satisfactory result, well within the accuracy limitations of heavy machinery. It is now necessary, for the best operation, to move the center of the "throw circle" until it coincides with the center of the machine. This means that, from Fig. 8, the shaft must be moved 0.0045 in. Downstream. This is done by readjusting the thrust bearing shoes.

After aligning has been completed, it is a good policy to make one last check for uniform shoe loading since that is the most important of the adjustments.

Practicable tolerances

In conclusion, it may be worth while to consider briefly the tolerances in shaft alignment of heavy vertical equipment. During the last two or three years many opinions have been voiced on this subject, and some very exacting demands have been made. There are definite, practical machining tolerances which cannot be economically surpassed. This means that there are very definite limits of accuracy which can be obtained when machining shafts as large as 36 in. diam, weighing in excess of 30 tons. It is not possible to machine such a shaft to an accuracy of 0.0001 in. with the present-day machine tools. Such accuracy, even if it were possible, is absolutely unnecessary for the satisfactory operation of vertical rotating machines.

To expect a large waterwheel generator shaft to show a "throw," during a rotation check, less than the total clearance of the turbine guide bearing, is sheer folly. Very satisfactory operation of such equipment can be obtained with a rotation check throw which is twice or even three times the total clearance of the turbine bearing. Demands for watch-like accuracy, beyond the limits already attained in the machining of this huge equipment, will run its cost far beyond the practical limits of economy without any improvement in operation or efficiency of the product.

ENGINEERING FUNDAMENTALS

Symmetrical components as an aid in determining voltage conditions for small motors.

The protection of small three-phase induction motors against single-phase operation is often accomplished by placing special lamps across the fuse terminals. If a fuse blows, the lamp glows. What is the voltage across the fuse? Does it vary with motor loading or speed? A consideration of symmetrical components supplies the answers.

Figure 1 shows a schematic diagram of the windings of a three-phase motor and indicates the voltage $V_{B'B}$ across the terminals of the blown fuse. From this diagram the following vector equations can be written (see supplementary symbols at the end of this article):

$$V_{CB}=V_{CO}+V_{OB'}+V_{B'B}$$

Transposing and solving for $V_{B'B}$,

$$V_{B'B}=V_{OC}-V_{OB'}+V_{CB}\ [\text{where } V_{OC}=-V_{CO}] \ldots (1)$$

Applying the method of symmetrical components,

$$V_{OC}=I_{C_1}Z_1+I_{C_2}Z_2$$

and $V_{OB'}=I_{B_1}Z_1+I_{B_2}Z_2$

also $V_{CB}=V_{AC}\,\underline{/120^\circ}=(V_{OC}-V_{OA})\,\underline{/120^\circ}$

$$V_{OA}=I_{A_1}Z_1+I_{A_2}Z_2$$

Equation (1) can then be written:

$$V_{B'B}=I_{C_1}Z_1+I_{C_2}Z_2-I_{B_1}Z_1-I_{B_2}Z_2 +(I_{C_1}Z_1+I_{C_2}Z_2-I_{A_1}Z_1-I_{A_2}Z_2)\,\underline{/120^\circ} \ \ldots (2)$$

In accordance with the theory of symmetrical components:

$$I_{A_1}=I_{C_1}\,\underline{/-120^\circ} \text{ and } I_{A_2}=I_{C_2}\,\underline{/120^\circ}$$

$$I_{B_1}=I_{C_1}\,\underline{/120^\circ} \text{ and } I_{B_2}=I_{C_2}\,\underline{/-120^\circ}.$$

Equation (2) can be rewritten:

$$V_{B'B}=I_{C_1}Z_1+I_{C_2}Z_2-I_{C_1}Z_1\,\underline{/120^\circ}-I_{C_2}Z_2\,\underline{/-120^\circ} +I_{C_1}Z_1\,\underline{/120^\circ}+I_{C_2}Z_2\,\underline{/120^\circ} -I_{C_1}Z_1-I_{C_2}Z_2\,\underline{/240^\circ}.$$

Collecting terms,

$$V_{B'B}=3\,I_{C_2}Z_2$$

Numerically, then, the voltage across an open fuse is three times the negative sequence voltage. See vector solution in Fig. 2.

The following examples can best be illustrated by using the per unit system and noting that the single phase line current is

$$I_L=\frac{1.0}{Z_1+Z_2}$$

Since $I_{C_2}=I_L/\sqrt{3}$,

then $V_{B'B}=\dfrac{\sqrt{3}\,Z_2}{Z_1+Z_2}$ .... (3)

(a) It is interesting to note that, with the rotor locked so that $Z_1=Z_2$, from equation (3)

$$V_{B'B}=\sqrt{3}/2=0.87.$$

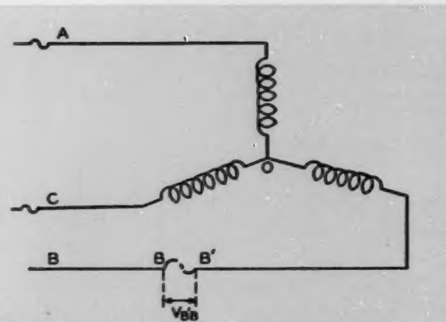


Fig. 1—Schematic motor diagram showing blown fuse and desired voltage $V_{B'B}$ across fuse.

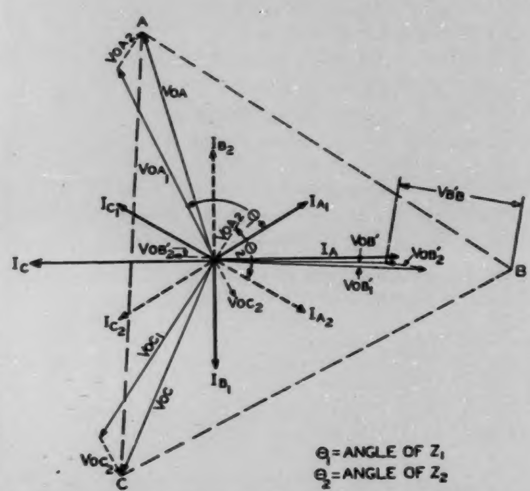


Fig. 2—Vector diagram showing voltage $V_{B'B}$ across open fuse when motor runs idle single phase

Simply stated, the voltage across the open fuse, when the rotor is locked, is 87% of the line voltage. This same percentage is obtained regardless of the motor frequency, number of poles, etc.

(b) If the motor is running at some value of speed, cognizance must be taken of the fact that Z_1 and Z_2 vary with slip. (Z_2, however, can usually be assumed as constant for a particular motor being considered.) $V_{B'B}$ will, therefore, vary with slip conditions. Since Z_1 is larger for high-speed machines, $V_{B'B}$ will be larger for slow-speed as compared to high-speed motors.

Assuming that a motor is capable of carrying full load when running single-phase, typical values of $V_{B'B}$ may be 50 to 60% of line voltage, the lower value being for the higher speed machines.

The following examples illustrate idle running; i. e., no-load, single-phase conditions.

Assuming that a 1200 rpm, 60 cycle motor running idle, single-phase, has a value of $Z_1=4.3$ (P. U.) and $Z_2=0.24$ (P. U.).

then $V_{B'B}=\dfrac{\sqrt{3}\times 0.24}{4.3+0.24}=0.092$ (P. U.),

or $V_{B'B}=9.2\%$ of the line voltage.

On the other hand a 450 rpm motor running idle, single-phase, has typical values of $Z_1=2.0$ and $Z_2=0.26$ so that

$$V_{B'B}=\frac{\sqrt{3}\times 0.26}{2.0+0.26}=0.20 \text{ (P. U.)},$$

or the voltage $V_{B'B}$ across the blown fuse will be 20% of the line voltage.

The ease with which the above problems can be solved serves to illustrate how useful a tool is the concept of symmetrical components to the induction motor engineer.

SYMBOLS

V = Voltage, subscripts refer to part of circuit for which vector is written.

I_{B_1} = Positive sequence current, phase B.

I_{B_2} = Negative sequence current, phase B.

Z_1 = Positive sequence impedance.

Z_2 = Negative sequence impedance.

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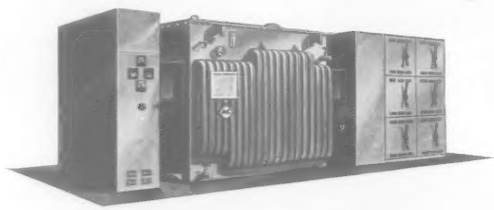
R. C. MOORE.



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FROM HEMP HAWSERS TO PROTECTIVE PAPER

From the war-besieged Philippines formerly came most of our manila hemp. But users of electrical insulating papers need have no immediate fears, for the supply of old rope shows no signs of vanishing.

E. G. Ham, **Technical Director**

JOHN A. MANNING PAPER COMPANY • TROY, NEW YORK

"Go to the ant, thou sluggard," was paraphrased at the beginning of the history of papermaking to, "Go to the wasp, thou papermaker," since genus *Vespa Crabo* was without doubt the first to manufacture anything like what we now call paper. The record of man's first attempt to make such a useful article tells us of the efforts of Ts'ai Lun about 105 A.D. in China. Over one thousand years passed before the paper manufacturing art reached Europe. About 250 years ago the first paper was manufactured in what is now our United States in a mill near Philadelphia. At present the manufacture of pulp and paper, combined with printing, is the fifth largest industry in our country; and the usefulness of paper, a product of cellulose, appears to be increasing continuously.

However, it is a far cry from the quality of the general-use paper, which includes a very great percentage of the 14,000,000 tons annual national production, to the highly specialized qualities required and found in modern electrical insulating papers. Most papers are made from comparatively short fibres, whereas the technical papers suitable for electrical insulation need to be composed of long fibres. General-use papers usually have a fugitive life and a short time of service. On the other hand, technical papers, making up important parts of electrical apparatus or current carrying elements, must be as permanent and stable a product as can be made from a vegetable material.

Paper made from manila hemp* has a rare combination of properties which makes it particularly suitable for this specialized purpose. It is logical to expect that paper made from this leaf-fibre has great tensile strength since from such fibres are made rope and hawser, the strength of which cannot be equaled by any other fibrous material of the vegetable kingdom. Not only do we find great tensile strength in papers made from manila hemp, but this is combined with great flexibility and extensibility, a combination of properties which is unique.

Problems of manufacture

To retain all the advantageous features of the parent fibre in a manila insulating paper requires a carefully developed manufacturing and control technique. Some such papers are as thin as 0.00085 in., which is not many times thicker than the diameter of the fibres used. For the manufacture of such products the conventional paper manufacturing procedures are employed with specialized modifications which have been developed through many years of experience.

Natives extract manila fibre, basic raw material for all insulating paper, on a hemp plantation in the now cut-off Philippine Islands.

Before discussing some of the steps in the manufacture of these specialized papers, it is well to consider just what a sheet of paper is. In many respects this useful article is similar to cloth, except that the fibres are not twisted into lengthy units which are woven. Instead, they are interlaced and laid down on a wire cloth from a water suspension. Paper manufacturing involves the felting of the individual fibres from the water suspension to form a continuous web of homogeneous character. After the laying down of the fibre by the felting process, the remaining water is carefully and slowly removed from the product by pressing and drying.

* Since this article was written before Pearl Harbor, some comment regarding the current supply of manila fibre is in order and may be found at the end of this article.

Cutting old manila rope in fibre preparation for paper making. Reprocessed fibre is chief source of hemp for the paper industry.

Variations in these processes have considerable effect upon the specific gravity of the paper. This effect may be further altered in a limited way by the use of calendering or dry pressing the product. For the many and various applications of manila hemp insulating paper ribbons and tapes to conductors of electricity, products of different degrees of smoothness, stiffness, and porosity may be required. Quite remarkable is the range of such properties, and these differences are in part due to variance in the different paper machine manipulations.

Manila hemp

In attempting to define electrical insulating paper, a description of the paper machine itself has been touched upon. Reverting to a short description of the method of preparing the manila hemp fibres for the manufacture of the web, manila hemp fibre in the form of discarded ship hawsers and other large diametered rope or new manila hemp from the Philippine Islands make satisfactory base material for insulating papers. Because the new manila fibre purchasable and that used in the manufacture of rope is marketed in various grades according to cleanliness, fibre diameter and strength, a careful sorting of the raw materials available is necessary in advance of the first steps in paper manufacture.

After this procedure, the long manila fibres are cut into about 3 in. lengths. These pass through a continuous pneumatic dusting system. Inasmuch as the manila in this form is composed of ultimate fibres bound together by semi-cellulosic or ligneous material, the latter must be softened or dissolved away to permit the dispersion of the fibres of nearly pure cellulose which are to be the basis of the manufactured paper. Fortunately, the ligneous binding constituents of the manila hemp bundles are readily dissolved in hot, weak alkaline solutions. Therefore a cooking process follows the cutting and dusting. The digested fibre is then freed from the softened and dissolved undesirable vegetable matter, along with the alkaline cooking residues, by a very efficient continuous washing procedure.

After the purifying process the long, silky manila hemp fibres remain and are ready for extensive refinement procedures which, when altered to suit the specialized variety of paper desired, are very important steps in the manufacture of satisfactory material. This refinement of the fibre, which entails changes in not only dimensional characteristics but also in those which govern water adsorption, is carried out in carefully controlled batch processings in tubs which are arranged with circulating propellers.

These propellers or rolls not only induce circulation of the fibre around the periphery of the tub, but such rotors can be adjusted for the amount of pressure they bring to bear on the circulating fibre. The fibre refinement in this element or "beater" is rather slow, sometimes beating periods of ten hours being necessary to induce desired fibre properties. The pressure of the adjustable roll on the fibres, which are in thick water suspension, is at first low; otherwise the manila would be prematurely shortened in length. After subjection to the intimate contact with the water by the action of the circulating propeller, however, the manila fibre builds up an immunity to being shortened; and it is believed that such effect is occasioned by the adsorption of water by the fibre. This change is also indicated by an evidence of increased gelatinization of the cellulose.

AT LEFT: Ready to be shaped on this huge hydraulic press is a record-breaking 76 inch, 190,000 pound ingot fresh from annealing furnace, which will be forged into a turbo-generator rotor.

Workmen packing cut manila fibre into cookers, where undesirable vegetable matter is dissolved away, leaving nearly pure cellulose.

The manipulation of manila fibre in the beater determines to a large extent the character of the paper which will be produced.

On this small-scale paper-making machinery in the research laboratory of a large manufacturer, new processes are first worked out.

A variation in the rate of pressure application from the beater roll very definitely determines the character of paper which will be made from the fibre. The range of variation of certain paper properties—such as specific gravity, porosity, tensile strength, stiffness and opacity — which can be obtained from paper machine technique variation, is small compared with the differences which can be brought about by varying the manipulation in the beater. Insulating paper tapes which are very strong, stiff, relatively non-absorbent and air resistant may be required for certain conductor covering applications. For others, such as the insulation of magnet wire, a very flexible, extensible, soft paper of medium strength may be required. In some cases the use of a paper of intermediate flexibility and strength is indicated. In either case the same quality of manila hemp is the base material, the differences in paper properties having been obtained by changes in the fibre processing and adjustments of the paper making machine.

Possible variations

In the foregoing description of the major processes involved in the manufacture of electrical insulating papers, no mention has been made of many secondary processes, control tests or control devices which are in continuous use. The necessity for such careful control from the beginning to the end of the paper making will be readily realized upon enumeration of some of the possible variations which might occur in the product. The most obvious variations would be those of paper thickness, ream weight and apparent density. Other evident and troublesome variations which must be kept at a minimum are:

- Tearing strength
- Folding endurance
- Tensile strength
- Flexibility
- "Formation" or homogeneous appearance
- Elongation under stress
- Surface finish
- Surface coefficient of friction
- Air resistance or porosity, its inverse
- Corrosion tendency

In addition to the possible variables in physical properties of insulating papers, those chemical in nature must also be vigilantly watched. Some of these variables are:

- Percentage of ash and its chemical constitution
- Titratable alkaline or acid residues in a water extract of the paper
- Hydrogen ion concentration of the water extract of the paper
- Resistivity of a water extract of the paper
- Water solubles percentage
- Alcohol solubles percentage
- Toluol solubles percentage
- Ether solubles percentage
- Copper number
- Chloride residues
- Sulphate residues

The value of chemical residue control in electrical insulating may be threefold, inasmuch as such chemical control affords an indication of (1) the aging properties of the product; (2) the electrical properties; and (3) the freedom of the paper from residues which might cause contamination of associated liquid insulation.

Applications

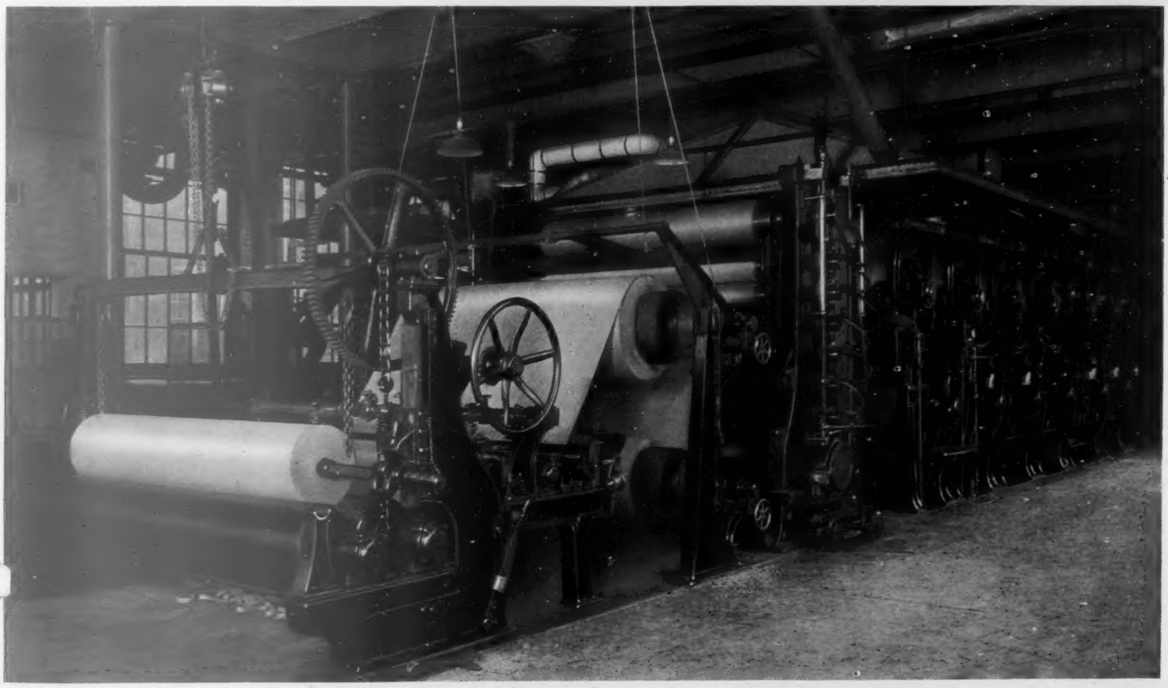
Much of the manila hemp electrical insulating paper is applied where the dielectric strength need not be high. Such an application is that of lamp cord conductor covering, in which case the strong, flexible manila paper tape is mainly a spacer between the conductor and rubber dielectric. In other applications the paper is applied as a sole dielectric, even unimpregnated, in which case the normal dielectric strength of the paper is sufficient for the application. The dielectric strength of such dry paper will range between 100 and 175 volts per mil thickness, the variation being dependent upon the relative flexibility and the apparent density of the paper.

In insulating applications where the paper is impregnated either before or after application to conductor or apparatus, the saturated dielectric strength of the paper is, in addition to being affected by the dielectric of the liquid, also somewhat dependent on the amount of the liquid which the paper will absorb. However, the most absorbent paper will not necessarily give the highest saturated dielectric strength because of the relative effectiveness of the barrier action of the fibres themselves. Obviously, the more fibres there are for such barrier action per unit volume of impregnated material and per unit volume of impregnant, the higher the dielectric strength will be.

Although the dielectric strength of paper insulation is a commonly used electrical test, other electrical properties such as power factor, dielectric constant and insulation resistance must be known and controlled to optimum values insofar as it is possible to do so. Such power factor measurements may be made on dry or impregnated paper at either high or low frequencies.

Electrical insulating papers of the type to which the foregoing refers are demanded and available in a large variety of physical dimensions. With papers which vary in apparent density between about 0.50 and 0.95 grams per cubic centimeter, the widest range is that of thickness, the variation demanded being between 0.00085 in. and 0.015 in., in steps ranging from 0.00015 in. in the very thin items to 0.001 in. steps in the heaviest rope manila insulating paper. The width range of insulating papers in spool or pad form varies between 1/32 in. width, in the case of the thinnest items, to 2 in. width in the case of the very heavy. It is obvious that, when it is known that some of the thin narrow paper tapes are wound onto copper conductors at a speed as great as 4500 rpm, care must be exercised in the elimination of all physical defects or weaknesses in this type of paper. So many provisions to insure cleanliness of product have to be made in a

Further refinements are incorporated into the paper in the commercial rope paper machine, which is shown here viewed from the dry end.



mill which produces electrical insulating papers that a complete enumeration of them would be out of place here.

The number of uses of paper for electrical insulation is increasing. At times when silk and cotton yarn coverings are scarce, wider utilization of paper for insulation purposes results.

* * *

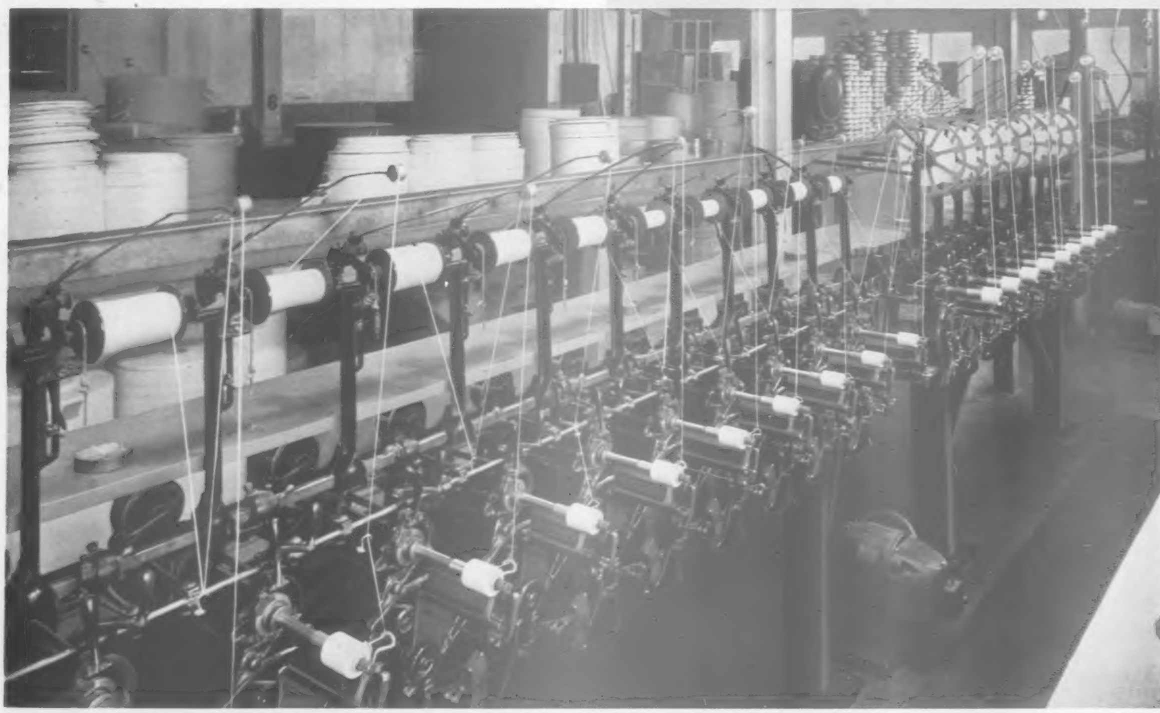
Because of the current international situation, some statement regarding the extent of the supply of manila hemp for the manufacture of insulating paper should not be amiss.

Manila fibre comes to the paper industry chiefly in the form of old rope. It is, therefore, dependent upon the amount of rope currently in use in ships operating on inland waters or touching at the numerous seaports of the northern hemisphere. It is difficult to estimate the total amount of potential old rope in this reservoir, but it is very considerable. Back of it are supplies of new rope in warehouses reserved for the Navy and merchant fleet and, behind that, supplies of new manila hemp impounded for the purpose of supplying the cordage manufacturers.

It may be seen from these statements that the immediate supply is assured and that the danger signal will be given by a gradual and not by a sudden and unexpected diminution in that supply. Such a change would naturally be followed by partial substitution in paper formulas of other high grade cellulose fibres to the extent necessary.

To safeguard quality, the moisture control panel above is in continuous operation during the processing of the fibre in the paper machine.

A complete electrical laboratory, in which the insulating paper undergoes rigid tests, is a vital part of modern paper manufacturing plant.



The finished insulating paper tape is wound on spools preparatory to its final packaging for shipment.

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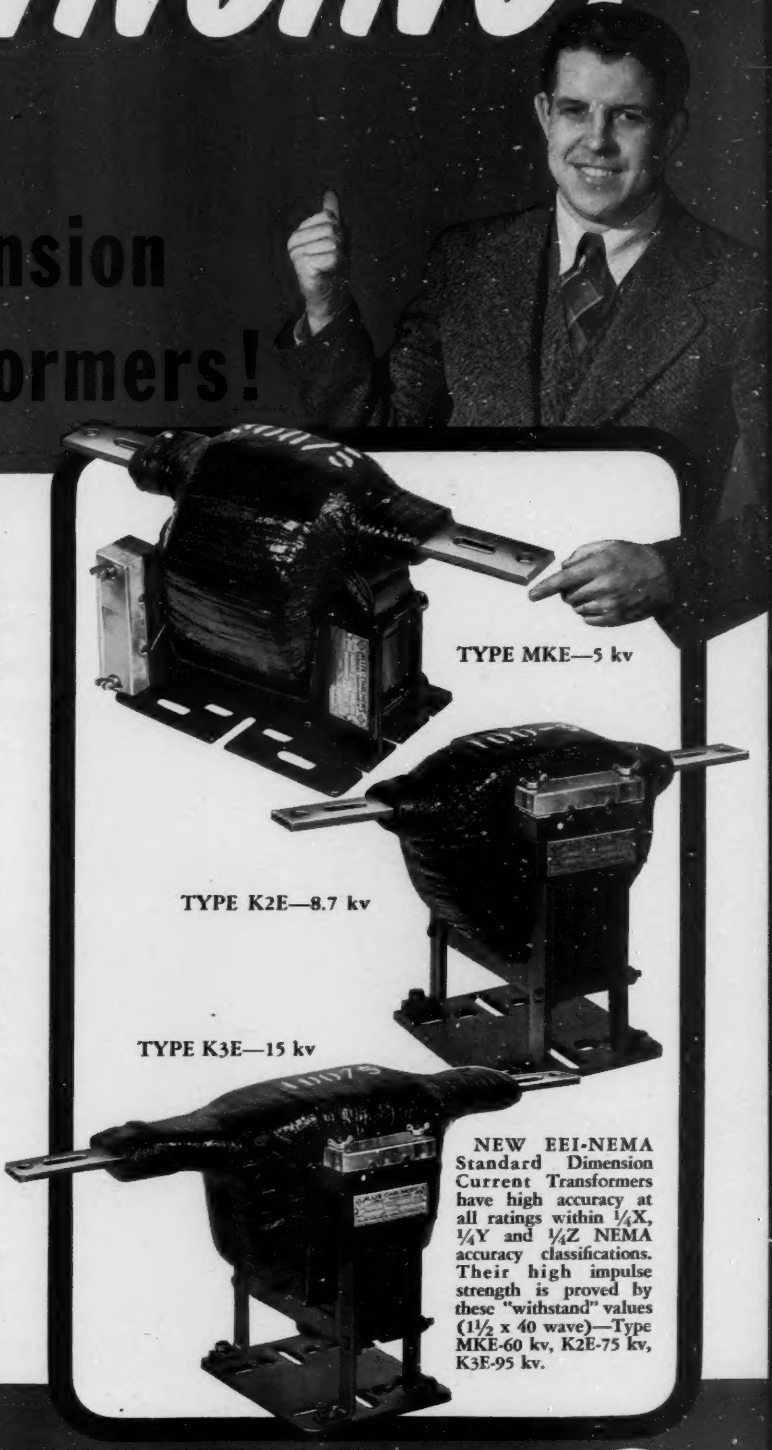

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